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BULLETIN
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American Association *of* Petroleum Geologists

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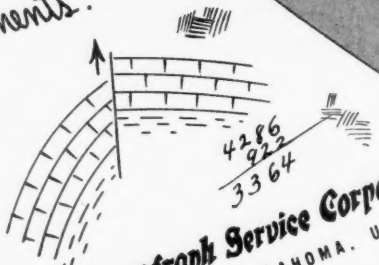

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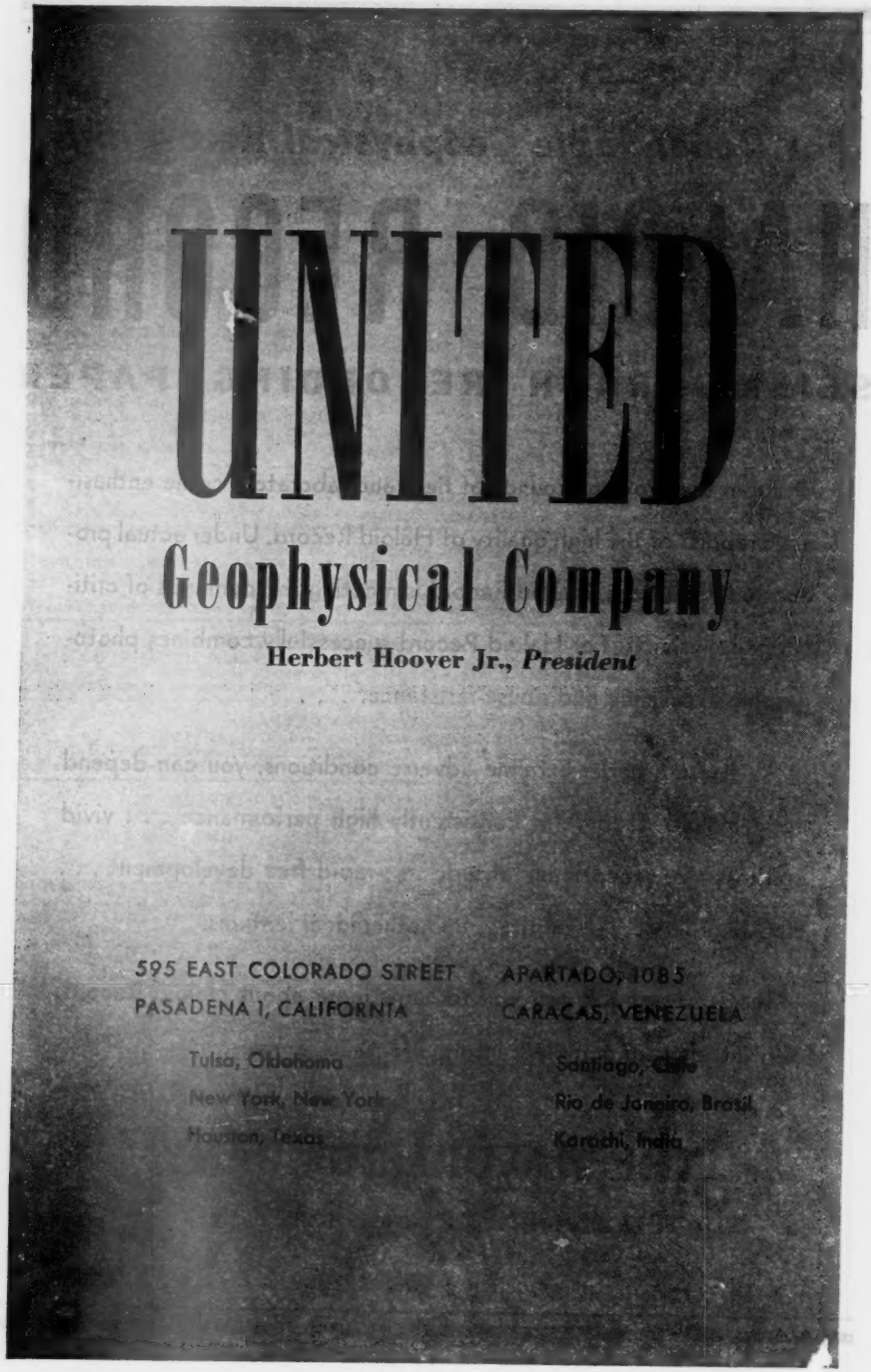
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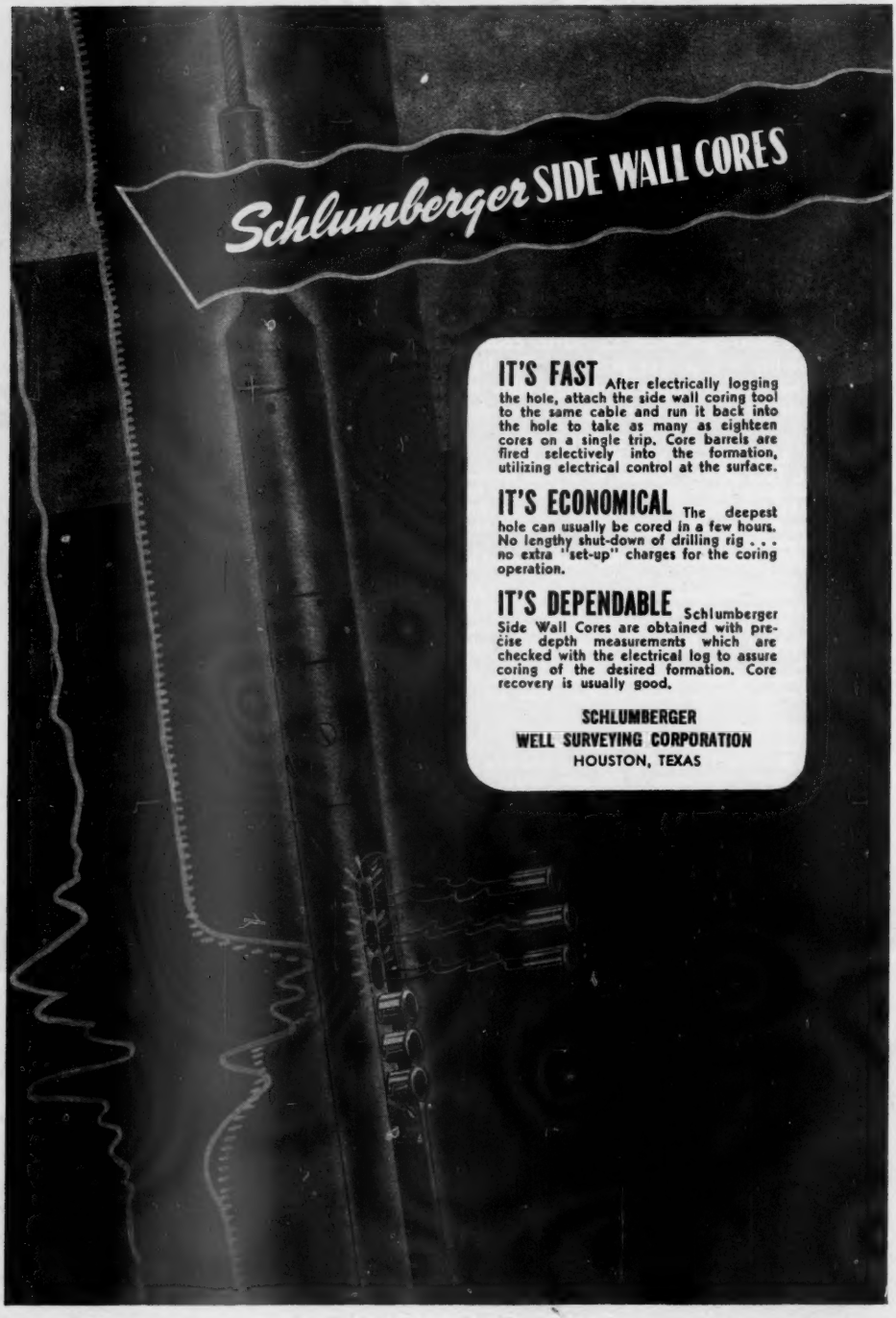
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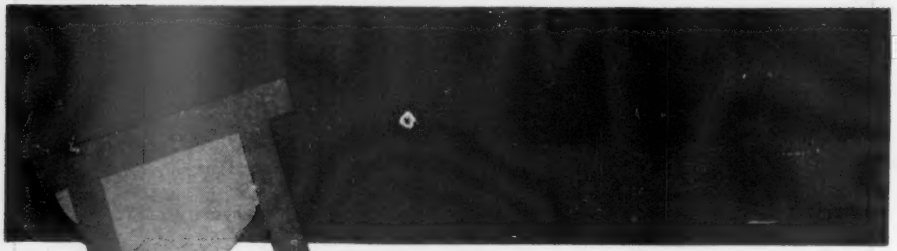

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IRA H. CRAM[2]
Chicago, Illinois

INTRODUCTION

This afternoon, in discussing the essentials of a college education in geology and the use of the various geologic tools, the point was made that although a petroleum geologist is a stratigrapher first and a structural geologist secondly, he has to be more than both—he has to be an earth scientist. During the short time spent in college, the best the geologist can do is to acquire enough of the principles of geology and other sciences pertaining to the earth to enable him to teach himself to become an earth scientist after graduation. The process of self-teaching further requires conditioning the mind to accept all earth data as geologic data and to accept any instrument that provides earth measurements as a geologic tool, regardless of whether or not the data and instruments masquerade as geophysical and geochemical, for instance.

But how useful is this fascinating and omnibus science of the earth? Have you, in effect, become experts in Sanskrit with a minuscule field before you? Obviously not! So let us explore in reconnaissance the untold opportunites for service which lie before you in both the scientific and commercial worlds.

GENERAL

Not so many years ago, when it was not an uncommon opinion in the halls of science that a petroleum geologist was a scientific renegade, petroleum geologists suspected that they were considered to have sinned because they dared to devote full time to the use of the science of geology in the solution of practical problems. If many of the geologists of those days considered geology as a science of more cultural than practical value, they may have been in tune with their times, but

[1] One of two lectures on petroleum geology delivered to the students of geology of the Universities of Minnesota and Michigan in 1947. Manuscript received, October 9, 1947.

[2] Assistant to the chief geologist of The Pure Oil Company.

such a view to-day would be out of step with our times. We are living in the age of applied science with the public conscious of the potency of science. The atomic bomb, penicillin, plastics, to mention a few items created by science, affect every person. With science moving ahead on a broad front at break-neck speed in an effort to solve more and more practical problems, geologists must not fail to keep pace by failing to apply their science to the full. Should they fail to keep up with with the parade, the machinery of advancement can well cease to function properly, because ordinarily progress can not be attributed to any one line of endeavor but to many working together, yet seemingly independently. There is a social angle. A scientist is not a privileged, cloistered individual apart from the peoples of the world; he is one of them with all their obligations, and with the added obligation of using his science to improve the lot of society.

Geology is useful, far more useful than any one of us knows, because no geologist is conversant with all the problems involving the earth, and the science of the earth can obviously contribute to the solution of all such problems. Truly, the field of applied geology is broad beyond any geologist's conception. Certainly I, with only limited experience, shall make no attempt to catalog all the uses to which geology has been put or will be. Rather I shall use the record of applied geology in the petroleum industry as a lesson in the intelligent utilization of geology and geologists. The record is one of which both the industry and geologists can be proud, and which any scientist seeking to apply his science can study to advantage. The non-scientist—the layman—can also study it to advantage, together with other examples of applied geology to be mentioned, and learn that geology as well as physics, chemistry, medicine, and other sciences, affects his way of life profoundly, that geologists are interested in making his existence more secure and comfortable in addition to being interested in dinosaur eggs, prehistoric man, volcanoes, earthquakes, and items that make the Sunday supplement. The impact of geology upon the individual can not be as dramatic and personal as a cure for cancer, for instance, but it is nevertheless real. Consider only the automobile age. Of the many factors making it possible, no one is more important than cheap petroleum products kept cheap by an abundant supply of crude oil. The rôle of geology in creating the abundant crude supply is no smaller than the rôle of cheap products in the development of the automobile age.

APPLIED GEOLOGY IN PETROLEUM INDUSTRY

Introduction.—During World War I, leaders in the petroleum industry, faced with increasing demand and declining discoveries, began to wonder if they had been right in their thinking that it was no trick to find oil, but that it took smart men to produce, refine, and market it. Perhaps the more philosophical among them were pondering the question of how many products their refiners could make out of an empty barrel of oil, to paraphrase Croneis' poignant remark. They turned to geology, reluctantly in many cases, and geologists came through not only with ample discoveries but with the solution to a great variety of miscella-

neous problems. The substitute lineman turned out to be a triple-threat half-back with a penchant for converting fumbles into touchdowns. Gradually it dawned upon a goodly percentage of oil men that the winning of oil from the earth is essentially a geological enterprise requiring a perfectly functioning team of geophysicists, engineers, scouts, land men, production men, drillers, managers, and others, quarter-backed by geologists. So, to-day geology permeates the oil business not because oil men love geology, but because geologists produce. Let us briefly sketch their accomplishments, while recognizing that it would have been a fiasco not to perform when the science of the earth was challenged to solve a critical problem involving the earth.

Exploration.—There are some interesting statistics that reflect the performance of geologists in exploration for oil and gas during the past 30 years. Since the beginning of the oil industry, approximately 33 billion barrels of crude oil and 66 trillion cubic feet of natural gas have been produced in the United States, 29 billion barrels and 57 trillion cubic feet during the last 30 years. During the same period, the estimated proved reserve of crude oil was increased approximately 18 billion barrels to the present total of approximately 24 billion, and the proved natural-gas reserve was increased between 136 and 146 trillion cubic feet to the present total of approximately 160 trillion. Finding 47 billion barrels of oil and between 193 and 203 trillion cubic feet of natural gas in 30 years was a prodigious feat, but what part did geology and geologists play? No answer in barrels or cubic feet is possible since discovery, by and large, results from team work, and few people are in a position to evaluate exactly the efforts of the various members of the team in all cases. A partial answer lies in the growth of the American Association of Petroleum Geologists during the same 30-year period from a membership of less than 100 to more than 5,000. Such a phenomenal growth does not take place if the services of the members are not in demand because of non-performance. Another answer lies in the present status of geology with respect to exploration. Scarcely a well of any importance is drilled in the United States to-day without benefit of geological advice, which includes geophysical advice. The advice may be acquired directly or indirectly, but it is nevertheless there. The services of geologists go further than merely giving advice. In one way or another they initiate and supervise most of the exploratory work now being done in the world. Had geologists failed during the last three decades, the services of some other breed of scientists would now be sought.

So geology is useful in the exploration for oil and gas. It is useful not merely because geologists can figure out the geology with a reasonable degree of accuracy by using the tools discussed this afternoon, but because the petroleum geologist has acquired judgment in appraising the economic significance of the geologic features uncovered by geological investigations. Expressing the same thought differently, geology is not useful until it is translated into economics.

It takes imagination as well as knowledge to deploy the geologic fact-finding machines so that oil is found instead of just more contours; so that positive infor-

mation is obtained instead of negative. This is no small chore since in the life of the petroleum industry only one fundamental principle governing the occurrence of oil and gas deposits has been developed, namely, important deposits of oil and gas occur only in traps in permeable rocks in sedimentary sections that are mainly marine in origin. And what are traps? They are not necessarily closed reservoirs with with so many feet of closure or so many cubic yards of lensing sand. They are not necessarily anomalies of the types that are known to produce oil. They are *any* kind of geologic anomaly that *can* hold oil and gas. These anomalies are not too hard to find, but which ones are the most likely to contain oil? Which ones are most worthy of testing with your company's money or your own? No machine will help you make these decisions for the gadget has not been invented, and may never be, which determines the presence of oil at depth directly. The petroleum geologist simply has to use his most important tool, his head, in making these decisions. How often do geologists reach the right economic appraisal of the geologic picture by using their handful of principles and theories and a lot of experience and imagination? Frequently enough to make their services indispensable in exploration is the answer.

Exploitation.—Geologists have made their services no less indispensable in exploitation. In the beginning of the 30-year period previously mentioned, the geologist was as welcome on a rig floor as smallpox. The driller knew what he was drilling in. Was not the earth made like an onion? The production man knew the rest of the procedure. What earthly good could a long-haired scientist be in the he-man, practical world of the oil fields? A combination of factors changed all that—the rotary drill, crooked holes, deep drilling, complex structure, the insistence of geologists that they could bring order out of chaos if given a chance.

And there was chaos on the Seminole uplift of Oklahoma where the rotary driller did not know one formation from another and, even worse, agreed with the production man that there was no such thing as a crooked hole. Geologists recognized early in the development important unconformities of economic value that they could determine unquestionably by the examination of well cuttings, if they had the cuttings. It did not take them long to suspect that the holes were crooked when the sub-sea contours on a given horizon looked like a combination of karst and glacial topography. Largely at the insistence of geologists, surveys were made of some of the more obviously crooked holes, and angles of as much as 45° with vertical corrections up to 800 feet were established. The cat was out of the bag! These geologists, after all, did have a "practical" idea now and then. Production men relaxed, gave orders to kick no more geologists off rig floors, gave further orders to fire the first driller who failed to collect samples or otherwise cooperate with the geologists. What had appeared to be a hair-raising problem in development turned out to be simple.

I have told this somewhat colored story of Seminole for, although geologists had been involved in production problems before, there had been no large-scale

employment of geologic talent in the solution of these problems. Thereafter, the presence of a geologist on a drilling well was mandatory. The need for better and better data on the subsurface section and its contents, hammered home by geologists, paved the way for the ready acceptance of geophysical and geochemical well-logging and core analysis. Geologists by performing again demonstrated the usefulness of geology, so that to-day they are an integral part of the oil-field develpment personnel. Their problems are varied. The mapping of oil fields in the greatest of detail for a number of purposes, including the making of locations for wells, is one of them. They also determine points to set casing, to perforate, to test, or to stop drilling and approve the plugging of a well as a dry hole, or the abandonment of an exhausted producer.

The geologist's understanding of oil and gas fields has led him into another application of geology—reservoir engineering. The problems of well spacing, optimum rates of production, pressure maintenance, secondary recovery and calculation of reserves, to mention a few, all require intimate knowledge of the structure and character of reservoir rocks possessed only by the geologist, to whom the physics and chemistry involved are intelligible. It was mentioned previously that approximately 47 billion barrels of oil have been discovered in the last 30 years. I should have said 47 billion barrels of oil that can be produced by present methods and at present prices. Everybody knows that a high percentage of oil discovered remains in the ground under present production practices. The actual amount of oil discovered may be as much as 50 per cent more than the figure of 47 billion barrels. How to *recover* a greater percentage of the oil already *discovered* is a pressing problem to which geologists are contributing and must contribute more through expansion of their work in the field of reservoir engineering.

The importance of adding exploitation to the geologist's sphere of activity can not be overemphasized. As a matter of fact, exploration does not stop with the completion of a discovery well for every well drilled in a field is a wildcat well to some degree. There is a distinct exploratory flavor to reservoir engineering. Actually the geologist is exploring for oil and gas until the field is exhausted and abandoned. The continuous study of oil and gas fields from cradle to grave has greatly increased geologists' understanding of the fundamental nature of these mineral deposits, and it should be self-evident that the better geologists understand oil and gas fields the more intelligently they can search for them.

Management.—The force of geology is now felt throughout exploration and exploitation and even further, for there are executives in the ranks of geologists. The man with executive ability and leadership may spring from any line of endeavor with no line having a monopoly on the creation of such men. Geology has its fair share of men with this talent, so it is only natural that these geologists in a business that is a geologic enterprise should become part of the management. Most of these executives are in the producing branch of the petroleum industry,

but with the general realization that all branches of the industry are dependent upon the producing branch, many of them are destined to climb to higher executive positions.

A man's method of thinking—of reaching decisions—is molded by his training in the line of work of his choosing. Geology teaches men the necessity of reaching decisions, however tentative they may be, by analyzing a miscellaneous assortment of incomplete data. A geologist is not instinctively afraid, therefore, of a problem that may or may not be geological and which would appear to the mathematician, for instance, to contain too many unknowns. The mathematician would look over the problem and conclude that it could not be solved. The geologist would recognize the "too many unknowns" as routine in his business, would dare to substitute reasoning and imagination for them, and come out with an answer together with an appraisal of the probable reliability of the answer. In other words, a decision is reached which is the caliber of the more daring business decisions, the kind that spells progress. Unquestionably the mental processes engendered by the science of geology are an important part of the make-up of those geologists who become executives. The geological mind has demonstrated its usefulness in the oil industry, and as a result a geological department becomes a catch-all for problems which no one else cares to tackle, and which may or may not be geological in nature.

APPLIED GEOLOGY IN MINING INDUSTRY

Judging entirely from what I read and learn from discussions with mining geologists, the mining industry is now in a position closely similar to that of the petroleum industry some 30 years ago when it turned to geology when faced with increasing demand and declining discoveries. Most estimators of the size of the proved reserve of critical minerals present a picture that is far from reassuring, and some are gloomy to the extent of forecasting that we may become one of the "have-not" nations in not so many years. With optimism as to the magnitude of the proved reserve of minerals being practically absent, it is clear that geology is again being dared to show its usefulness.

To date, the mineral industry has not had to depend on large-scale scientific exploration for its supply of raw material, just as the oil industry did not have to prior to 30 years ago when random wildcatting and drilling on surface indications resulted in an ample supply. With the scene changed to exploration for hidden deposits, it would appear to be crystal clear that mining men could well afford to study the history of exploration for, and exploitation of, oil deposits during the last three decades, and adopt the philosophy and those procedures that seem to apply to the problems of mineral discovery and recovery. This entails acquiring a spirit of exploration on the part of mining men who pay the bills, some of whom after spending a lifetime thinking in terms of reducing costs a few cents a ton will tend to rebel against spending the kind of money it takes to finance scientific exploration and exploitation on a full-time, not a part-time, basis.

It is just as geologically preposterous to assume that there are no more large mineral deposits in the United States as it is to assume that there are no more important petroleum deposits to be found. Deposits of both are here; they just happen to be hidden from view or are only faintly suggested at the surface. Quoting Lasky,[3]

> For every major mining district there are dozens that contain only insignificant prospects or a few small mines. These meager showings may represent the upper reaches of larger or richer deposits below. What would the area look like if another 1,000 ft. or 500 ft., or even 200 ft., were removed by erosion? Many mines have more than one productive zone, separated by low-grade or barren intervals hundreds of feet deep. Moreover, extensive bodies of recent rocks may cover and conceal older centers of mineralization comparable in size and value to our active mining districts.

An oil geologist might have written the same general statement of principles as applied to oil deposits by changing a few words, thusly:

> For every major oil-producing district there are several that contain only insignificant showings or small oil fields. These may represent the near surface indications of larger and richer oil deposits below or in the vicinity. What would the area look like if the wells were drilled another 3,000 ft., 5,000 ft., or even 10,000 ft. deeper? Many oil fields have more than one productive zone, separated by barren intervals hundreds of feet thick. Moreover extensive areas of unmappable rocks may cover and conceal oil fields comparable in size and value to those already discovered.

An oil geologist, if presented with this statement 30 years ago, probably would have remarked, "Perfectly true and perfectly meaningless from a practical standpoint." *Of course,* he could not know *at that time* how he was going to help find approximately 5 times as much oil and more than 6 times as much gas as had been found in the previous 58 years, but the fact remains this much oil and gas were found in 30 years by a pioneer-spirited industry employing geology and geophysics. And the fields found were in "impossible" formations, in "impossible" traps, in "impossible" areas, at "impossible" depths, and of "impossible" size. It took new tools intelligently deployed with results carefully interpreted, close analysis, coordination, and imaginative interpretation of all new facts discovered, and, above all, ideas and mental fortitude on the part of geologists.

Can not geologists turn in a similar performance for the mineral industry by adopting a similar procedure? No one can say it is not in the geologic cards. Without question mineral geologists are not so bankrupt of principles and ideas that they can not make an intelligent start and ultimately accomplish that which may now seem to many to be the impossible. But they must be encouraged to make the necessary intense regional and local geological investigations, to explore the usefulness of all geologic tools, be they geophysical or geochemical, to work actively in exploitation as well as exploration, and to think daringly. In other words, mineral geologists must be permitted by the mineral industry to spread their

[3] S. G. Lasky, "Ore Reserve Viewpoints, *Min. and Met.*, Amer. Inst. Min. Met. Eng., New York (September, 1946), p. 468.

wings on a full-time basis, not a consulting basis, if the nation's undiscovered reserve of minerals is to be developed.

APPLIED GEOLOGY IN ENGINEERING

The usefulness of geology is not limited to the exploration for, and exploitation of, mineral deposits. The field of engineering geology, which is the application of the science of geology to the requirements of engineering, is growing rapidly. As in petroleum and mining geology practically no phase of earth science is not brought into play in engineering geology. Also, a detailed record of accomplishments in engineering geology is as difficult to obtain, if not more so, than the accomplishment records of petroleum and mining geology because of the private nature of much of the work and the meager literature on the subject.

It is, of course, obvious to any geologist that geology can be utilized in any construction project. Fifty years ago geologists seldom participated in these projects, but after construction engineers learned the hard way that serious errors could have been avoided by consulting geologists, they began to invite in these earth specialists. To-day, geologists play an important role in many important private and Governmental engineering projects, such as dams, reservoirs, tunnels, canals, aqueducts, buildings, bridges, highways, and railroads. All these demand accurate knowledge of the nature of foundations, best contributed by geologists who can recognize and understand the significance of shear zones, joints, faults, depth and character of bed rock, *et cetera*. Geologists more familiar than I am with the present rôle of geology in construction admit progress has been made but see that the services of geologists could be greatly expanded to advantage. The trend is toward constructing bigger and bigger dams, reservoirs, buildings, bridges, *et cetera*, which certainly must be built on the best possible natural foundations as determined by geologists.

Geology has long been used in problems involving underground water. The question of supplying water of sufficient quality and quantity is often acute, and promises to become more acute as cities and towns, and particularly the industrialized ones, increase in size and number. The United States Geological Survey and certain State surveys have rendered outstanding service to a great many communities with water-supply problems.

Every military man does not know, but every geologist does, that the study of a terrane for military operations requires consideration of all the surface and subsurface geologic data obtainable. These data may be abundant or few—perhaps the only source is what can be gleaned from an aerial photograph or a topographic map—but, in any event, it takes a geologist to piece together the bits of evidence on the true nature and significance of the terrane. Innumerable construction projects—earthworks of all kinds, trenches, dugouts, air fields, docks, water supply, *et cetera*—have to be carried out with speed under trying conditions necessitating the services of engineering geologists. The geologist's ability to interpret maps of all

kinds is of inestimable value. It is unnecessary to pursue the subject further because the value of geology in two world wars has been demonstrated beyond question. All of us have heard sentences and paragraphs out of the long and exciting story of the uses of geology in World War II. The final story, when told, will be truly amazing, and one of the most amazing parts of the story will be the uses to which geology was *not* put because of the poorly informed admirals and generals.

CONCLUSION

I shall not proceed further with this rough analysis of the usefulness of geology because even the non-geologist in the audience should by now recognize that geology is one of the more practical sciences. The history of geology in the oil business is the best of lessons in applied geology because in this enterprise geologists, when given a fair chance to spread their wings, produced and found geology to be even more useful than anybody had dreamed it could be. The more petroleum geologists delivered, the more rope they were given, and they still are not through extending the sphere of their usefulness.

Geologists have not had the same chance to apply their science in mining and engineering, but progress has been made and additional opportunities will unquestionably present themselves. It is up to geologists, and particularly the younger geologists, to see to it that they do not muff the ball when it is handed to them. It is even more necessary that they do not wait for the ball to be handed to them, that they force the breaks of the game, pick up and run with the fumbles, steal the ball. In other words, geologists must be alert to any and all possibilities of extending the uses of geology, and must sell their ideas to the proper people rather than wait for the proper people to contact them. The dynamic instead of the passive approach has worked in petroleum geology, always works when one has something worth while to sell.

There are those geologists, and I am one of them, who believe that geology has not been accorded its fair place in the sun. A better than partial remedy to this sad state of affairs is to aggressively extend the application of geology, and to tell the world about it. Perform first, publicize secondly. In the oil country everybody from the bootblack to the banker recognizes that geology is useful, not because petroleum geologists have ballyhooed it, but because they have produced. By applying geology to the solution of more and more practical problems, the science and every geologist, including those scientists who are interested only in the scientific aspects of geology, will benefit.

Which reminds me that in my zeal to stress the value of applied science, I may be accused of overlooking the contributions of the host of excellent geologists who devote their lives to what is usually known as pure science. On the contrary, I am not making such a colossal error because geologists applying the science realize perhaps better than the pure scientists themselves the usefulness

of the latter's contributions and the need for more and more such contributions. Recall the story of Cumberland[4] this afternoon. We were attracted to the area partly by Dr. Decker's study of the Simpson group[5] of Oklahoma, a study in pure science published for the use of all geologists. It is doubtful if Dr. Decker studied the Simpson just because he knew it contained oil in parts of Oklahoma, but if he did, more credit is due him for coordinating his efforts with those of the economic geologists. If every geologist, regardless of occupation, slants his efforts toward making the science more useful, no difficulty should be experienced in keeping up with the scientific parade.

[4] Ira H. Cram, "Case History, Cumberland Oil Field, Marshall and Bryan Counties, Oklahoma," *Geophysical Case Histories*, Soc. Explor. Geophysicists (in press).

[5] Charles E. Decker and Clifford A. Merritt, "The Stratigraphy and Physical Characteristics of the Simpson Group," *Oklahoma Geol. Survey Bull. 55* (June, 1931).

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WILCOX (EOCENE) STRATIGRAPHY, A KEY TO PRODUCTION[1]

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ABSTRACT

Wilcox (Eocene) sedimentation, stratigraphy, and production are discussed. Present productive trends are explained by interpreting the regional deltaic sedimentation and stratigraphic history, which are discussed and illustrated diagrammatically. A restored strike section from eastern Alabama to southwest Texas shows graphically the near-shore sedimentary conditions at the close of Wilcox time. A table giving the productive sands in Wilcox fields in Texas, Louisiana, and Mississippi through 1945 is included. Data and information are taken entirely from published sources.

INTRODUCTION

The very nature of the (Eocene) Wilcox with its variable sand horizons, its great thickness and lateral extent, and lack of diagnostic foraminiferal zones signals to the stratigrapher and sedimentationist that the problem of research is going to be slow and fragmentary (Ferguson and Casey, 1942, p. 42).

Gulf Coast geologists and operators are familiar with the history of discovery and early development of Wilcox production (Todd and Roper, 1940, pp. 705–06; Ferguson and Casey, 1942, p. 41), beginning with the Urania field in LaSalle Parish, Louisiana, in 1925, continuing at Kittrell and Clay Creek domes in Texas, but gaining major impetus only in 1937 with the discovery of Wilcox production at Joe's Lake (Spurger) in Tyler County, Texas. In 1940 and 1941 drilling was accelerated along the Wilcox trend, with the result that many fields were producing from zones in the Wilcox within the next several years (Table I).

Each Wilcox well drilled supplies additional information to the already vast and rapidly increasing body of data concerning sedimentation on the Gulf Coast during Eocene Wilcox time. Therefore, it is desirable from time to time to take stock of the information accumulated, to reorganize it, and to re-evaluate it in the light of stratigraphic theory and principles. By so doing, it becomes possible to formulate a provisional interpretation of Wilcox history which can serve as a basis for future study and exploration. All of the information made available by intensive drilling since 1937 is being used to further the search for, and the discovery of, oil in the Wilcox deposits.

Structural and sedimentary phases of this tremendously thick lower Eocene body of sands and shales have been discussed by the various authors who have written on this subject, and many interesting sedimentary facts have been uncovered. It has been interesting to note the growth of ideas that have evolved as

[1] Manuscript received, August 1, 1947.
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[2] Geologist, Pond Fork Natural Gas Company.

[3] Paleontologist, Shell Oil Company, Inc.

information has become available and geologists have been able to piece together more and more of the depositional history. Culbertson (1940, pp. 1891-1922), whose paper is the most complete published subsurface study of the Wilcox, logically interprets the stratigraphic history as a retreat of the strand line at the end of Midway time, continuing well into the middle Wilcox time, followed by extensive deltaic deposition on a slowly subsiding coastal plain, ending with transgression or advance of the strand line in late Wilcox time. There is now general acceptance of this history and agreement concerning the deltaic nature of the

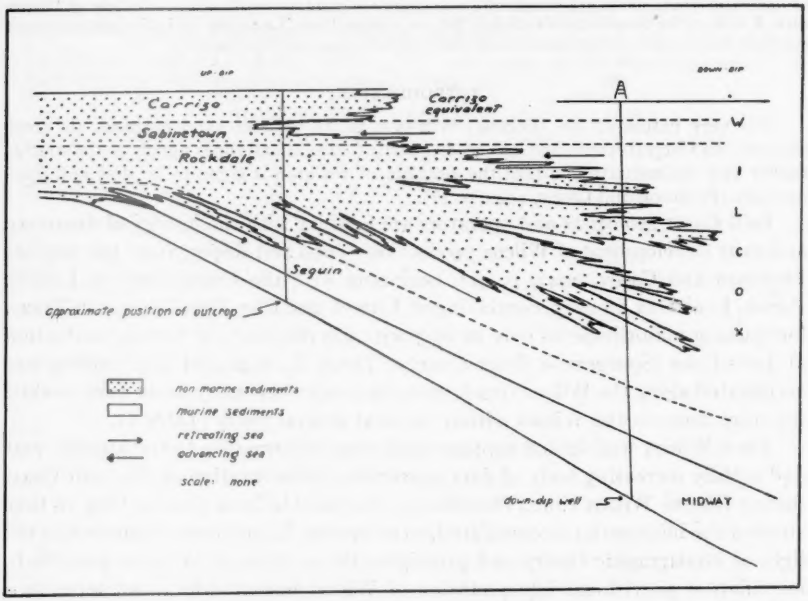

FIG. 1.—Generalized dip section of Texas Wilcox sediments. Not drawn to scale.

great middle part of the Wilcox group, composed predominantly of continental, estuarine, and littoral deposits. Culbertson's paper and the Houston Geological Society's Wilcox publication (Houston Geological Society, 1940) contain numerous electric-log dip profiles and correlations, useful in presenting a pic ure of subsurface conditions. These and other publicly available data have been used in compiling the diagrammatic representation of the depositional history shown in Figure 1.

For several years the writers have been studying with interest the sedimentary facts as they were disclosed during consistent Wilcox exploration; they

present this paper as an attempted organization of the stratigraphic principles revealed by their study. The numerous references listed have been used freely in compiling the facts. As all of the data were acquired from sources available to the public, the work represents an interpretative composite picture based on published work to date. The writers have tried to present a plausible regional interpretation of the complex history, seeking to explain the erratic sand conditions and the "spotty," unpredictable nature of Wilcox production. The theories are set forth with the hope that discussion and criticism will be evoked. The explanations and interpretations may be proved erroneous or impractical by new and more complete information obtained from more numerous deep wells, downdip drilling, and closely spaced wells, or by data in company files (not available to the writers during preparation of the paper).

STRATIGRAPHY AND PRODUCTION OF WILCOX GROUP

The Wilcox (Eocene) group includes for the purpose of this discussion all of the sedimentary beds between the marine Midway underlying it and the marine Claiborne above. Subsurface zonation and correlation of the Wilcox are thus far difficult to establish because subdivisions are not readily discernible in the subsurface, definite fossiliferous zones are rare and ordinarily not traceable regionally, and subsurface correlations of the numerous sand bodies and shale breaks are not reliable even locally. These factors have greatly hindered the unraveling of Wilcox sedimentation problems.

A restored strike section prepared from published data[4] represents conditions existing at the close of Wilcox time and shows the correlation of the several surface units comprising the Wilcox group in Alabama, Mississippi, Louisiana, and Texas (Fig. 2). The section presents graphically the near-shore deposits from eastern Alabama to the southwest Texas Rio Grande embayment at the close of Wilcox time.

The outstanding physiographic elements influencing the distribution of the sediments can readily be discerned. The predominant features are the two large deltaic masses, evidently at the mouths of two ancient river systems, the "Wilcox Mississippi" and the "Wilcox Colorado-Brazos." In these areas non-marine, cross-bedded sands, interbedded with sandy clays and lignite, predominate. Between the deltas, and interfingering with the deltaic sediments, are deposits of estuarine, lagoonal, littoral, and neritic origin, representing the interdeltaic embayments. These are found in Alabama, the Sabine-East Texas area, and the Rio Grande embayment area.

From the near-shore section, a history of events during Wilcox time can be interpreted, since it is here that changes in sedimentation are more evident than in a section farther removed from the oscillating shore lines.

[4] See entries marked with asterisk (*) in reference list.

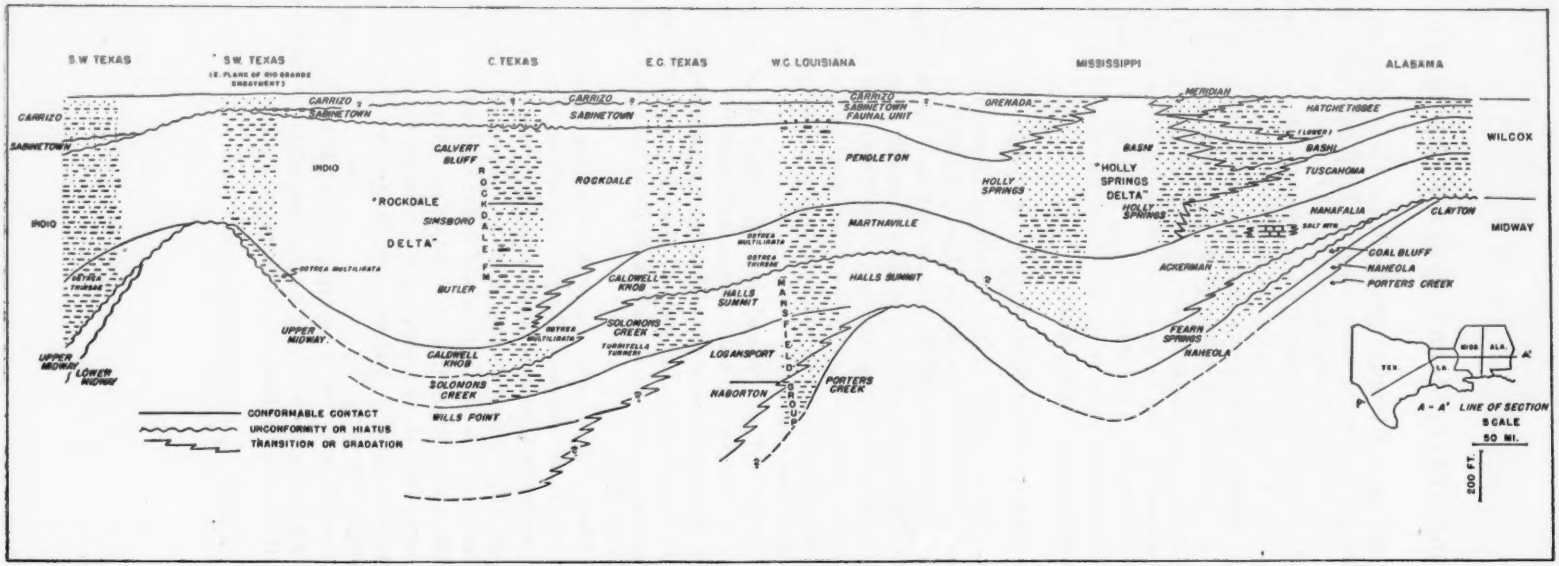

FIG. 2.—Restored strike section representing updip conditions at close of Wilcox time.

The history of the Cenozoic era is a history of the transgressions and regressions of the marine waters, and the correct interpretation of the geology depends upon the knowledge of the remarkable intergrading and interbedding of the two types of sediments, the continental and the marine, as well as the recognition of the intermediate types, the littoral and lagoonal sediments. Not only does one type of sediments replace the other vertically, as the Wilcox land deposits replace the Midway marine strata, but also, if some formational units are traced laterally far enough, one facies may grade or change abruptly into another (Plummer, 1933, p. 527).

The Wilcox sediments appear to have been deposited during an extensive regression and a transgression of the sea.

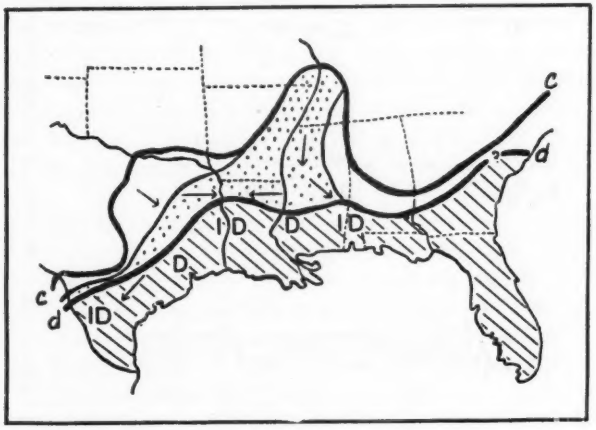

FIG. 3.—Wilcox Gulf Coastal Plain (after Schuchert) showing
(a) approximate known extent of predominantly marine Wilcox (shaded areas);
(b) non-marine sediments (dotted areas);
(c) minimum inland extent of Midway seas (c-c);
(d) retreat of sea since Midway (areas inside heavy line d–d);
(e) deltaic areas (D), and interdeltaic areas (ID).

LOWER WILCOX

Stratigraphy.—The lower Wilcox sediments were deposited during a retreat of the sea. Preceding the earliest Wilcox the Midway was a time of extensive marine deposition. Marine silts, clays, and fossils indicate that the minimum inland extent of Midway seas was approximately as shown in Figure 3. Toward the close of Midway time retreat of the seas from the basin areas was accompanied by a change in sedimentation. The marine shales and clays of the Midway gave place to the coarser, less marine clastics of the Wilcox. The contact of the Midway with the Wilcox is said to be disconformable. The absence of a widespread unconformity, however, obviates the probability of a rising landmass terminating Midway deposition, and suggests rather a climatic change, the un-

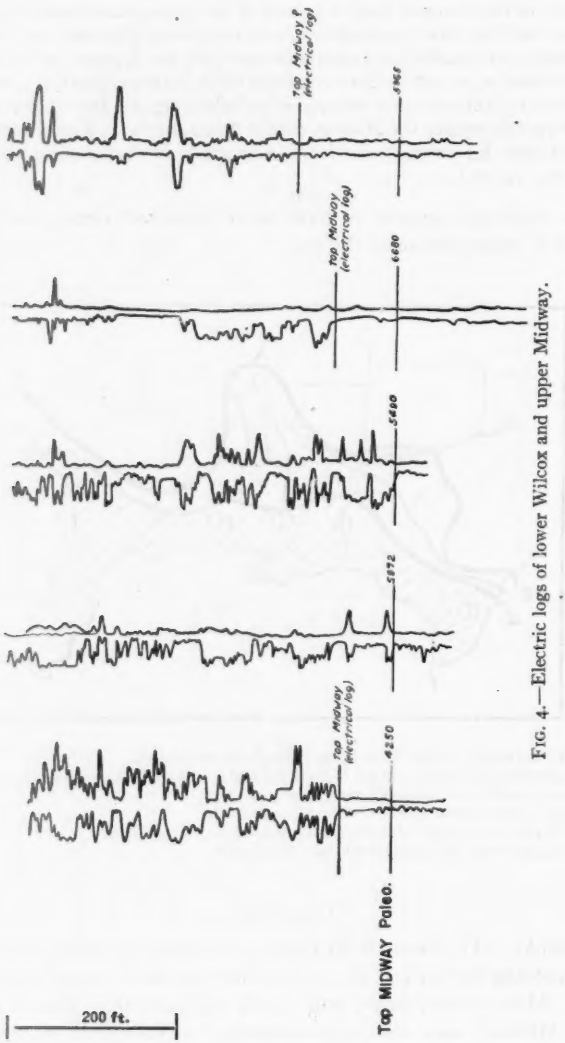

FIG. 4.—Electric logs of lower Wilcox and upper Midway.

covering of coarser source rocks, and possible isostatic adjustment, with the influx of coarser sediments accompanying the recession of the strand line.

Apparently the growth of the "Wilcox Mississippi" delta was more rapid since it was from Mississippi that the sea retreated first, both to the east and the west, as evidenced by the presence of non-marine early Wilcox sediments there. Marine conditions persisted in the Alabama and East Texas basins, and also in the "Brazos-Colorado" delta area, until the end of lower Wilcox time. The beach sand that occurs locally at the top of the lower Wilcox represents the regressive sand of the offlapping upper Midway-lower Wilcox sea. In the surface marine areas the lower Wilcox beds can be differentiated from the Midway deposits only with difficulty. In the subsurface the Midway-Wilcox contact is usually chosen arbitrarily on electric logs at the base of the lowest Wilcox sand body in most areas; but in fact ques ion exists as to where the real contact is in many places where the lower Wilcox is shale. The lack of a marked unconformity indicates that the contact is transitional, and under such conditions, in some places the shales assigned to the Midway might well be a facies of the Wilcox, and in other places the lowermost sand on the electrical log might represent deposition during late Midway time.

Figure 4 shows the lower part of the Wilcox and the upper Midway on five elec ric logs. It is noted that the stratigraphie determinations of the Midway formation top from samples differ from the electric-log contact. If faunal and lithologic zones in the Midway and Wilcox were traceable updip and downdip and along the strike it would be possible to construct a series of paleogeographic maps illustrating the varying rapidity of retreat of the Midway sea.

Production.—Because of the conditions of their deposition, lower Wilcox sedimentary beds do not seem as favorable for production as those higher in the Wilcox section, and it will probably be many years before the possibilities are thoroughly investigated. In updip wells the lower Wilcox sand is overlain by continental sands of the middle Wilcox, and thus lacks an effective impervious seal. In downdip areas, where marine conditions continued longest, the sands may not retain their porosity and permeability.

Only limited data on the porosity and permeability of the Wilcox sediments are available to the writers (Culbertson, 1940, pp. 1920–21; Houston Geological Society, 1940). Tests made on sediments from 7,500 to 9,000 feet and below 9,000 feet indicate that the porosity and permeability decrease with depth. For example, from 7,500 to 9,000 feet 19–22 per cent porosity and from 0 to 900 millidarcys permeability are reported from wells in nine fields and three wildcats; below 9,000 feet, 7–20 per cent porosity and 0 to 200 millidarcys permeability are recorded. The statistical validity of such a small sampling might be questioned, but it might be safe to assume that downdip wells which must penetrate 15,000–16,000 feet of sedimentary beds before reaching the lowest Wilcox sands will generally encounter unfavorable reservoir conditions, although these will be found to vary locally and may be satisfactory in some places.

MIDDLE WILCOX

Stratigraphy.—The middle Wilcox was a period of great delta building. The history is that of a major retreat of the sea into a slowly subsiding Gulf of Mexico. The sediments laid down are for the most part non-marine sands, lignites, and clays at the surface, with interbedded marine zones downdip. This part of the Wilcox group comprises as much as four-fifths of the entire Wilcox.

The lower Wilcox retreat continued, so that during middle Wilcox time the sea was driven out of most of the Gulf Coast area except in restricted basins where marine conditions persisted. Along the margins of the basins and at the constantly changing limits of the deltas, oscillating shore lines left marine beaches, offshore bars, and brackish-water lagoonal clays, causing interfingering of the marine sands and shales with deltaic sands and muds. These grade into non-marine shales, lignites, and sands of the two major coalescing deltas, here termed the Rockdale delta (of the Wilcox Colorado-Brazos) and the Holly Springs delta (of the Wilcox Mississippi). Ultimately the deltaic areas were built so far out from the original position of the Wilcox shore that deepest downdip drilling to date has not yet found a completely marine middle Wilcox section. Somewhere in the Gulf of Mexico there should be a complete marine shale and silt section which was deposited contemporaneously with the delta sediments.

> The thickness of the Wilcox indicates a gradually subsiding area during Wilcox deposition, permitting marine transgressions, and at times it failed to keep pace with abundant sediments from the land, with the consequent temporary filling of areas of accumulation. Actual occasional uplift is suggested by unconformities in certain areas and may be proved when better correlations are established, but, for the most part, periodic subsidence of a flat plain with proper climatic conditions offers sufficient explanation of the thickness of the Wilcox deposits (Culbertson, 1940, p. 1894).

The hinge along which subsidence took place must have been at least as far inland as the early Wilcox shore line, to account for the progressive rapid downdip thickening of the middle Wilcox sediments.

Apparently retreat of the sea took place into the basin areas from all landward directions. The sedimentary record of the Alabama embayment indicates that the sea withdrew to the east in Alabama, since marine conditions persisted longer in eastern Alabama, and sections in western Alabama and eastern Mississippi are non-marine. From western Mississippi the non-marine sections probably grade westward into marine beds in south-central Louisiana. The basin probably became restricted in area as the seas retreated into it simultaneously from west and east when the rate of deposition was greater than the rate of sinking of the basins. In Texas, evidence should also be found for contemporaneous retreat of the sea into the Rio Grande embayment during at least part of the middle Wilcox.

The complex combination of features associated with fluviatile, alluvial, palustrine, deltaic, and littoral sedimentation, interfingering with neritic deposits, comprises the record of middle Wilcox conditions. A possible interpretation of the regional history has been attempted, to explain the general trends of pro-

ductive sands, and at the same time the erratic, discontinuous distribution of the sands. The record of an extensive, far-reaching retreat of the sea, accompanied by very slow subsidence, is written in the sediments. From the record may also be read the cause for the heterogeneous, discontinuous nature of these sediments. Alluvial material was built progressively farther out into the Gulf, grading into marginal deposits. Pre-existing features were reworked, not once but many times, not only by the rivers which flowed out over the extending alluvial or deltaic plains, but also by repeated oscillations of the sea margin and invasions of marine waters. Several significant results are deducible.

A.—Though trends remain, few, if any, lithologic units are traceable for any distance in any direction, because of the erratic nature of the deposits themselves, and because the reworking of the deposits probably destroyed any original continuity.

B.—Marginal sands (where non-marine or transitional conditions of deposition grade into marine facies) tend to be well sorted as a result of repeated reworking. These sands grade into less permeable lithologic units and can form stratigraphic traps for petroleum accumulation. The traps are probably not correlatable except as their comparative positions can be related to adjacent, more continuous marine units.

C.—A number of types of sand bodies result, such as sand wedges ("pinchouts"), beach sands, offshore bars and barrier beaches, beach ridges, distributary ridges on deltas, deltaic sands, alluvial and outwash sands.

Because they possess the necessary qualifications of nearness to source sediments, and gradations in permeability, several of these types may be considered as potential petroleum reservoirs, namely, sand wedges, beach sands, offshore bars, barrier beaches, and beach ridges. Bars and beach ridges are discontinuous features, but they do occur in trends. All of the types were probably broken up and dissected by streams as retreat of the strand line took place and they became subjected to subaerial erosion or to the deposition of continental sediments over them. This hypothesis in itself would help to explain the fact that it is impossible in some areas (small fields in La Salle Parish, Louisiana, such as Big Island) to drill offset wells to the same depth on strike, and to be certain of production in the second well when the first is productive.

D.—An added factor is closely related to the arcuate, or scalloped coastline resulting from deltaic sedimentation. Each major deltaic area is of course made up, like the present Mississippi delta, of numerous small deltas, on each of which is a distributary pattern of drainage. N. C. Smith (1942, pp. 30–36) has pointed out that a permeability "closure" results from the gradation in three directions of the permeability of sediments in an arc such as would exist in front of a distributary on a delta. After floods, the distributaries change position, the position of the arc is moved, and a permeable area may, as a result, overlie an impermeable area. Many such shifts would result in a multitude of sand lenses, with no correlation in depth or in time. It seems possible that this may be one of the major explanations

TABLE I

FIELDS PRODUCING FROM WILCOX SANDS*
(O=oil; G=gas; D=distillate; Cz=Carrizo)

TEXAS

County	*Field*	*Wilcox Top (Depth in Feet)*	*Productive Sands (Depth in Feet)*	*O/G/D*
Angelina	Ginter	? 2,186 (Cz)	2,186	O
	Redland	? 1,021	1,021	O
Austin	New Ulm		9,151–65	O
	Orange Hill	8,953	9,052–67	G/D
			9,080–9,145	G/D
			9,137–64	G/D
			9,270–9,307	O
	Sealy		8,700–24	G/D
			8,724–87	G/D
Bee	Berclair	9,820 (Cz)	10,020–150	G
			10,080–120	G
			10,100–144	G
			10,370–404	G
	Burnell		6,985–93	G
	Cosden		7,110–25	G/D
			7,210–20	G/D
			7,240–50	G/D
			7,390–98	G/D
	Erp		7,974–78	O
	Mineral		7,460–7,511 (Cz)	G/D
			7,587–95	G/D
			7,850–75	G/D
	North Pettus	(See Karnes County)		
	Plummer-Wilcox		6,974	O
	Ray-Wilcox		7,581–96	G/D
	South Caesar	6,443 (Cz)	6,479–6,507 (Cz)	G/D
		6,557 (Wx)	6,504–57 (Cz)	G/D
			6,611–55	O
	South Tulsita-Wilcox		7,030–59	O
	Spielhauyen ?		7,334–38	G
	Voss-Foley		8,300–10	G/D
			8,530–40	G/D
	West Tuleta	−7,200 (?)	7,505–16 (Cz?)	O
			7,574–88 (Wx)	O
			7,587–95	O
Brazos	Millican	−3,026	3,342–48	G
			3,104–07	G
Colorado	Altair		8,256–8,136	G/D
	Chesterville		9,500–40	G/D
	Columbus		7,820–60	O
			7,302–14	G/D
			7,667–70	O
	Frelsburg		8,177–82	O
			8,475–95	D
			8,860–8,930	D
			9,280–98	D
	Garwood West	9,423	9,423–35	G/D
	Glasscock		9,216–26	O
	Hamel		9,032–75	O
	Inglehart		8,780–8,800	D
	Ramsey		8,320–40	G/D
			8,948–70	G/D
			10,250±	G/D

* Data compiled from: *Oil Weekly, Oil and Gas Journal*, annual reviews in *Bulletin* of American Association of Petroleum Geologists, *Rinehart's Oil News, Lockwood's Reports, Petroleum Development and Technology* volumes of American Institute of Mining and Metallurgical Engineers, for the years 1939–1945.

TABLE I—(*continued*)

County	*Field*	*Wilcox Top (Depth in Feet)*	*Productive Sands (Depth in Feet)*	*O/G/D*
	Rock Island		9,680–95	D
			9,274–80	D
	Sheridan	7,902	8,138–43	O
			8,746–56 ?	O ?
			9,360–87	G/D
			10,168–403	G/D
			10,750–785	?
	Sublime		9,500–05	O
	West Orange Hill		8,368	G/D
DeWitt	Cottonwood Creek		7,627	G/D
	Nordheim	6,991	7,027–30	O
			7,161–71	G/D
			7,363–90	G/D
			8,110–40	G/D
			8,216–28	G/D
	Thomaston	7,735	7,855–85	O
			7,900–22	O
	Warmley		7,085–90	O
	Yoakum		8,160–90	G/D
	Yorktown	7,070	7,192–7,204	G/D
Fayette	Arnim		2,040–60	O
	Cistern	1,650	2,808–18	G
			2,867–70	O
Goliad	Albrecht		8,340–60	O
	Boyce		7,470–7,500	G
	Cabeza Creek	7,325	7,645–76	G/D
			7,743–60	G/D
	Slick Wilcox		7,658–63	O
			7,600–20	O
			7,564–79	O
	South Cabeza Creek		8,306	D
	South Weesatche		8,490	G/D
	Weesatche		7,979–84	O
	West Goliad		11,182–92	O
Hardin	Olive		10,012–049	O
Karnes	Belknap		7,031–35	G/D
	Burnell		6,743–50	G/D
			6,750–90	G/D
	Coy City		7,144–49	G/D
	Falls City		4,651	O
	Green		6,537–43	O
	Hobson	4,029	4,000–10 (Cz)	O
			4,021–24	O
	Hysaw		3,922–76	O
	Klingeman		7,880–7,916	G/D
	McCaskill		7,404	G
	North Pettus	6,942 (Cz)	6,943–63	G/D
			7,000–7,020 (Cz)	G
			7,060–90	G/D
			7,320–55	G/D
			7,398–7,400	G/D
	Porter		7,400 (Cz-Wx)	G/D
	Runge		6,598–6,677 (Cz?)	O
LaSalle	New Mexico		6,030–55	G
	Washburn	3,223 (Cz)	4,822–41	G
		3,513 (Wx)	5,090–5,104	G/D
			5,130	G
			5,415–30	
			5,909–82	

TABLE I—(*continued*)

County	*Field*	*Wilcox Top (Depth in Feet)*	*Productive Sands (Depth in Feet)*	*O/G/D*
	NE. of Catulla (14 mi. S. of Fowlerton)		4,706–14	?
Lavaca	Brushy Creek	7,620	7,725–58	G/D
			10,000–11,000 (3 sands)	?
	Hope		7,716	G
	Provident City	8,486 (Cz-Wx)	8,746–90	
	Seekamp		7,700–50	G/D
	Vienna	7,600?	8,463–8,506	G
		7,566?	8,491–8,509	O
	Word		5,872–77	G
Liberty	Cleveland	9,041	9,050–9,150	G
	McCoy		9,108–9,135	O
Live Oak	Albert West		6,720–26	O
	Chapa		8,127	G/D
			8,144–93	O
	Coquat		7,460–84 (Cz-Wx)	O
			7,452–48	O
	Goebel	6,843	6,970–82	O
			6,903–70 ?	G/D
			7,050–80	G/D
			7,081–90	O
	Kittie West		6,705–11	G/D
	Oakville-Wilcox		6,956	G/D
McMullen	Green Branch	3,955	3,934–41 (Cz)	O
			3,955–65	shows
			5,720–32	G
	Loma Alta		6,866–69 (Cz)	O
	San Caja		6,439–6,553 (Cz)	G/D
Montgomery	Deering Creek ?	8,650		
	Lake Creek	8,400–8,500 (Approx.) (–8,200)	8,798– 8,808	
			9,185– 9,200	
			9,230– 9,245	O
			9,734– 9,754	
			9,754– 9,793	G/D
			10,992–11,022	
			11,348–373	O
			11,508–533	G/D
			11,775–815	G/D
	Magnolia	8,221 ?	8,445–58	G/D
	Pinehurst	8,635	8,760–66	O
			9,700–26	G/D
			9,564–9,622	D
			11,050–095	D
	Willis ?	6,750		
Polk	Ace (deep)	7,720	7,748–62	O
			7,810–20	O
	Livingston		6,986–7,012	
			7,021–29	O
			7,038–52	O
	Schwab	7,826	7,826 ?	O
	Segno	8,120	8,000–18 ?	O
			8,163–68	
San Jacinto	Shepard	8,318	Top to 8,590 (Several sands)	G/D
	Cold Springs		7,883–7,915	O
	Mercy	8,209	8,206–89	O
			8,314–22	O
			8,372–77	O

TABLE I—(*continued*)

County	*Field*	*Wilcox Top (Depth in Feet)*	*Productive Sands (Depth in Feet)*	*O/G/D*
Tyler	Camp Eleven	7,885	7,997–8,008	O
			8,000–15	O
			8,024–35	O
	Fred	8,180	8,180–8,200	O
			8,434–36	O
			8,612–35	O
	Joe's Lake	7,641	7,652–70	O
	Rockland		3,415–33	O
	South Hyatt		8,374–82	G/D
Victoria	Mission Valley		8,402–07	G/D
Washington	Clay Creek	?	Shallow	O
Webb	Bruni	8,938 ?	Blowout	
			8,953–56	
	Retamia		4,962	G/D
Wharton	Lissie	9,415	9,518–93	D
			9,614–20	G/D
			9,655–81	G/D
Wilson	Poth	2,690 (sands)	4,082–95	O
	Stockdale		5,145–54	O

LOUISIANA

Parish	*Field*	*Wilcox Top (Depth in Feet)*	*Productive Sands (Depth in Feet)*	*O/G/D*
Allen	So. Oberlin	8,442 ?	12,650–659	O
Avoyelles	Eola	8,513 ?	8,536–56	O
Beauregard	Neale	8,330–50	8,356	O
			10,880–896	O
			10,974–11,004	O
			11,532–574 (9 sands)	O
	West Pinegrove		11,343–350	O
Caldwell	East Caldwell		2,754–59	?
Catahoula	Lake Larto (Big Slough)	3,938	5,112–17	
	North Catahoula Lake		4,294–98	
	North Lake St. John		4,434–43	O
	Manifest		1,810–17 (Sparta-Wx)	O
	Muddy Creek	3,274	4,708	
	Trout	2,315	3,171	
	Willow Lake	3,723–57	5,533–37	
	Wildcat	2,845	3,874–95	O
	Wildcat	4,134	5,406–16	
Concordia	Ferriday	3,427	4,567–71	O
	Lake St. John	3,374	3,490–3,520	O
			3,928–36	
			4,435–42	
			4,567–92	O
			4,615–37	
	Wildcat		3,400–10	O
Evangeline	Pine Prairie	9,848	Several	
			10,158–280	O
			10,440–539 (3 sands)	O
	Mamou		11,510–533	O

TABLE I—(*continued*)

Parish	*Field*	*Wilcox Top (Depth in Feet)*	*Productive Sands (Depth in Feet)*	*O/G/D*
	Reddell	10,494	10,620	
			10,794	G/D
			10,822	G/D
			11,131	G/D
			11,191	O
			11,380	O
			12,020	G/D
			12,041	O
			12,113	O
	Ville Platte	9,850	9,850	
			10,055–085	O
			10,118–157	O
			10,148–170	O
			10,230–245	
La Salle	Big Island (See Rapides)	3,938	5,152	
			6,096	
			6,862 ?	
	Big Slough (See Catahoula)			
	Catahoula Lake	2,732	3,543	
	Clarks (Kelly) (See Winn)			
	Cypress Bayou	3,121	4,755–60	
	Elm Ridge		4,572–75	O ?
	Hemphill	2,563	Several	
			3,450–3,680	
			3,950	
			4,100–25	
	Indian Bayou		4,294–98	O ?
	Little Creek	1,754	Many	
	(Zenoria)		2,384–2,625	O
			3,000	
			3,500	
	Nebo	2,563	Many	
			3,450–4,160	O
	North Nebo	2,578	3,340–3,420	
	(South Jena)		3,418–32	
			3,840	
	Olla	1,613	2,225	O
			2,950±	
			2,758–75	O
	South Olla	1,780	2,270–2,415	
	(Summerville)		Several	
	Urania	1,500	1,500	
	Walters		4,757–62	
	3 mi. E. of Nebo		3,897–3,900	O
Rapides	Big Slough (See Catahoula)			
	Flatwoods		6,488–94	O
	South Catahoula Lake	3,962	4,294–98	
			5,144–54	
			5,784–92	
	Big Island	3,938	5,152	O
			6,096	
			6,862 ?	
Tensas	Holly Ridge		3,012–24	O
	North Lake St. John		4,435–43	O

TABLE I (*continued*)

Parish	*Field*	*Wilcox Top (Depth in Feet)*	*Productive Sands (Depth in Feet)*	*O/G/D*
Winn	Clarks (See La Salle)	1,611	2,173–76	
	Standard	1,587	2,165 2,375 2,475±	
	Urania-Tullos (See La Salle)	1,500	1,500	
		MISSISSIPPI		
County	*Field*	*Wilcox Top (Depth in Feet)*	*Productive Sands (Depth in Feet)*	*O/G/D*
Adams	Cranfield		5,880–84	O

for the multiple uncorrelative Wilcox producing sands, of no great lateral extent even within fields. A table of the producing sands in the Wilcox (Table I; see fields in northern Louisiana) illustrates an example of this effect. It may also be observed in the Lake Creek field, Montgomery County, Texas, as well as in many others.

Not only is the shifting of the distributaries (and thus of the arcs of shoreline) an important factor in positions of sand "pinch-outs," but perhaps even more significant is the effect of oscillating shorelines during this time. Alternating minor advances and retreats of the sea would tend to vary the outline of an arcuate coast, with an effect exactly like that described for changes in distributary pattern.

Figure 5 explains more clearly the nature and effect of the shifting of the permeability "closure." This diagrammatic picture, superimposed on a map of the Gulf Coast, illustrates the possible development of multiple-reservoir sands in the middle Wilcox.

At "A" stage, the middle Wilcox littoral and inner-neritic zones are assumed to be inside of position "I," resulting in the development of characteristic shoreline features: arcuate coast, coalescing deltas, offshore bars, shore beaches, barrier beaches, and lagoons. "Ideal distribution of sediments by waves in near shore areas is characterized by a gradation of coarse to fine particles seaward" (Smith, 1942, p. 36). Therefore from the shore margin to the open Gulf, porous zones might be laid down grading outward to impervious zones of finer-grained sands and interbedded shales. "There may be a tendency for the arcuate contour of the coastline to be transmitted to the internal texture of the offshore deposits" (Smith, 1942, p. 36). Assuming that such a pattern was transmitted to the offshore deposits, the resulting features would be excellent reservoirs for petroleum.

At "B" stage in the diagram it is assumed that the sea has encroached upon the land, and near-shore features similar to those developed in "A" are developed

between "B" and "2." At position "C" the shoreline is developed seaward, the sea having retreated, and the characteristic sand deposits in the area between "C" and "3" are in some places laid down, separated by a considerable thickness of shale, over the earlier shoreline features. Sands -A- and -C- are both possible productive zones, and a well drilled at "X" would penetrate and (if oil had accumulated) produce from both bodies, whereas a well drilled at "Y" would miss the porous zone in -A- and tap production only in -C-. At "Z," -A- would produce and -C- would be barren. Figure 6 shows the resulting series of deposits in cross

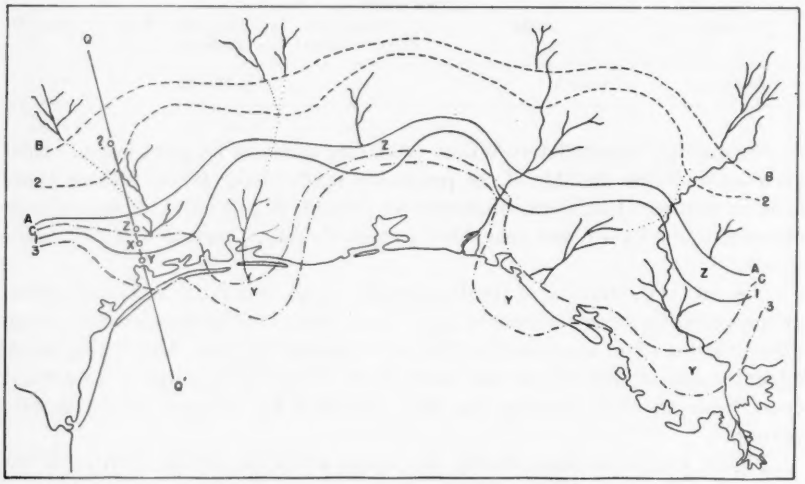

FIG. 5.—Diagrammatic interpretation of permeability "closures" on Gulf Coast.
At A Stage littoral and inner-neritic zones are between A–A and 1–1.
At B stage littoral and inner-neritic zones are between B–B and 2–2.
At C stage littoral and inner-neritic zones are between C–C and 3–3.
X position of possible production in sands -A- and -C-.
Y position of possible production in sand -C-.
Z position of possible production in sand -A-.

section. Although Figures 5 and 6 are regional diagrams, the same stratigraphic features should be found in local areas.

The nature of the middle Wilcox interstratified sands and shales suggests that these processes might have continued throughout the entire section of middle Wilcox. In general, reservoirs would be in rough trends, but production from the trends would vary, some areas being represented by multiple-sand production, other areas by single-sand production, and in still other areas all potential sand zones might be barren or impervious.

"Internal sedimentary texture," or the distribution of sediments within offshore deposits, is of major importance in determining whether or not the deposit

will be petroliferous. Local sedimentary conditions also play a vital role in affecting specific areas of deposition, and cause modifications and variations in kind of material, permeability, and porosity. Therefore in considering a sedimentary interpretation, it is essential to keep in mind the influence of environmental factors such as turbidity, offshore and near-shore currents, and original surfaces and sites of deposition.

Production.—Early discoveries in the Wilcox were in uppermost Wilcox sands (Urania field, Louisana; Joe's Lake field, Texas). Now much deeper production is known, not only from one zone in the deeper Wilcox, but from numerous distinct sand bodies in many fields. The entire downdip middle Wilcox series of alternating shales and sands, and the alternating sands and shales along the oscillating shorelines, appear ideal for exploration, but the lack of a correlating pattern

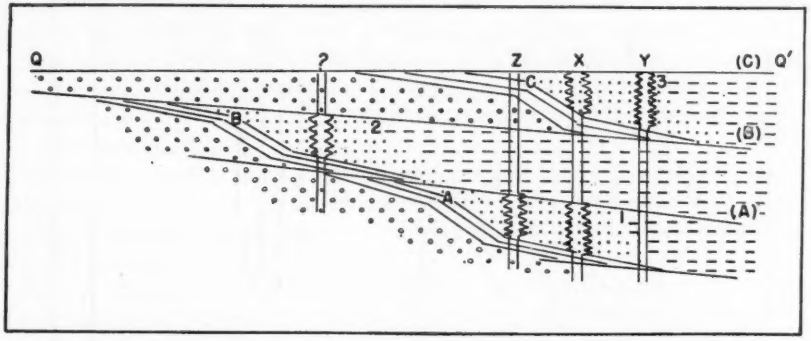

FIG. 6.—Cross section of deposits shown in Figure 5.

makes estimates of the depths of producing zones hazardous, even where structures are known to be present. Although a regional trend of production is apparent, there is no consistent pattern representing the positions or number of possible producing sands.

The strictly sedimentary treatment of this problem presents a theoretical picture which might explain the presence of regional Wilcox trends, and at the same time, the laterally and vertically erratic nature of the petroliferous sands within the formation. Although this is a strictly sedimentary discussion and the reference to structure is therefore necessarily brief, the writers are aware of the vitally important role of structure in influencing productive trends.

For an ideal approach to the Wilcox problem, a thorough study of Gulf Coast structural history should be coupled with as thorough a sedimentary and stratigraphic study. Stratigraphic versus structural traps as petroleum reservoirs have have been widely defined and discussed; but the necessity for the presence of favorable conditions in both together is now apparent in the Gulf Coast. Past

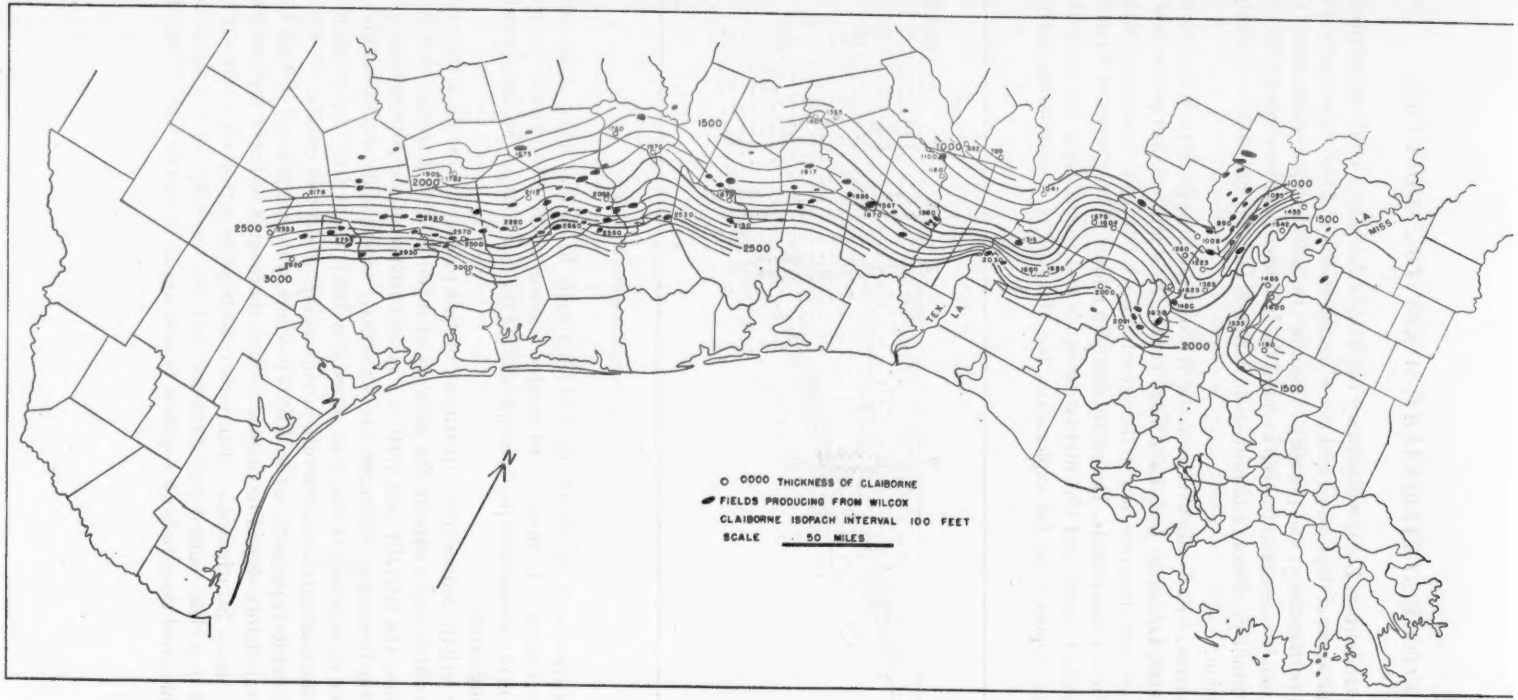

FIG. 7. —Isopach map: base of Yegua to top of Wilcox, in coastal area of Texas, Louisiana, Mississippi.

drilling in the Wilcox seems to indicate that the most favorable areas are those associated with major structural trends and related local normal faulting and folding. Such structural areas with favorable reservoirs and source sediments should offer the greatest petroleum possibilities or the largest resources (Culbertson, 1940, p. 1922).

The Gulf Coast geosyncline was an important feature of Eocene sedimentation. Any dip section shows the tremendous thickening of the Wilcox downdip (into the geosyncline). The limitations of the drill, however, make it impossible at present to penetrate the complete section of downdip Wilcox, so that complete data on the rate of progressive gulfward thickening are lacking. However, marked thickening is seen in north-south profiles in the section immediately overlying the Wilcox (the Claiborne). Figure 7, a map of the coastal area, shows isopachal lines based on the Claiborne interval from the base of the Yegua to the top of the Wilcox. The trend of known deep Wilcox productive fields that are producing from the middle Wilcox tends to follow the line of marked increased downdip thickening in the Claiborne. Without the complete Wilcox interval, it is imposible to determine the position of the axis of the geosyncline in Wilcox time. Wilcox oil accumulation trends may be related either to the axis, or to the edge or "jump-off" of the geosyncline.

Middle Wilcox production should be associated also with the marginal configuration of the two great deltas, the Rockdale delta and the Holly Springs delta. As this configuration was constantly changing, productive trends were affected as described in the previous section.

With present data, and with the increasingly available amount of new data, it is advantageous to reconstruct in detail the history of local areas from careful study of samples and electric logs, and by developing paleogeographic maps and isopach maps, noting thicknesses, changes in lithologic character, porosity, and permeability, and the distribution of lithologic conditions. Regional and local features controlling accumulation of oil in the middle Wilcox sedimentary beds will then be discernible.

UPPER WILCOX, AND CARRIZO

Stratigraphy.—The upper Wilcox formations are sandy and shaly, less lignitic and carbonaceous, and more marine than the underlying deltaic deposits. The base of the Sabinetown is in many places a beach sand (Fig. 2), lying disconformably on the middle Wilcox. After the culmination of the great middle Wilcox retreat, the sea slowly readvanced over western Alabama, eastern Mississippi, and most of Texas. This transgression began in late middle Wilcox time, so that by the end of Sabinetown (late Wilcox) time marine conditions existed over most of the Gulf Coast area. So far as can be inferred from the evidence at hand, non-marine conditions continued in Mississippi to the end of Wilcox time. The beach sands at the base of the upper Wilcox represent the basal transgressive sand of the overlapping upper Wilcox seas. In updip wells the first sand below the Carrizo sand

(where present), identified as the top of the Wilcox, is the basal transgressive sand of the Sabinetown. This sand is much older, or stratigraphically lower, downdip becoming increasingly younger toward the outcrop, so that downdip the Sabinetown equivalent is a marine shale, and the first Wilcox sand encountered in downdip wells is much older than surface Sabinetown.

The Carrizo formation was deposited during a minor regression between the late Wilcox and the Claiborne transgressions. It is a non-marine sand, overlying the Sabinetown in Texas, disappearing downdip and eastward along the outcrop. Transitional Wilcox-Claiborne material in Louisiana overlies the Wilcox, and may be correlative with the Carrizo. Part of the Grenada sand, and the Meridian sandstone in Mississippi may be stratigraphic equivalents of the Carrizo. It is suggested that the Hatchetigbee, which was deposited at the close of Wilcox deposition in Alabama in a marine environment, represents in part at least a marine equivalent of the Carrizo (Roy and Glockzin, 1941, pp. 744–45; Houston Geological Society, 1940).

The lithologic difference between the Carrizo and its possible equivalents is attributed to difference in source and depositional environment. The relative purity of the Carrizo quartz sand is an indication that it was not derived from the erosion of the underlying impure Sabinetown formation, but rather from a pure sand which inland erosion had uncovered, for example, possibly the Paluxy (Plummer, 1933, p. 616).

In updip wells in Texas, the subsurface Carrizo is identified as the first sand below the Claiborne shales and is immediately underlain by Wilcox sand with the contact in many places undeterminable. As the section is traced downdip, shales separate this sand from the first Wilcox sand and the two sands can then be separately identified. Still farther downdip the Carrizo sand pinches out and is represented by marine shale equivalents, probably partly Wilcox and partly Claiborne in age. There the first pre-Claiborne sand is Wilcox, either Rockdale (middle) or basal Sabinetown (upper) in age. In Louisana where Carrizo sand is generally not present, the top of the first sand is Wilcox. It is thus evident that neither a time plane nor a stratigraphic horizon is being contoured when contours are drawn on top of the first sand below the Claiborne shales. For practical purposes, however, such contouring has proved satisfactory, although more careful distinction, if this is possible, would more clearly show the true depositional and structural picture.

The history of the upper Wilcox-Carrizo has been interpreted as follows: The Sabinetown of Texas and the Hatchetigbee of Alabama, deposited in a progressively advancing sea, are represented by beach deposits at the base and by deeper-water sediments above and downdip. At the close of Sabinetown deposition, apparently a retreat took place in Texas and Mississippi. In Texas, the sea retreated from north to south, and from the central part of the state to both the eastern Texas and the Rio Grande embayments. In Mississippi the sea retreated eastward to Alabama, where the Hatchetigbee sea continued into Claiborne time.

As the retreat continued, coarser continental sands (Carrizo and Meridian) were deposited disconformably or unconformably on the Sabinetown and Bashi, respectively (Fig. 2.) The limit of the Sabinetown retreat eastward from Texas is marked by the disappearance of the Carrizo lithologic conditions at the Sabine uplift. The limit of the retreat toward the south in Texas is marked by the disappearance of the Carrizo along an approximate zone through southern Live Oak, central Bee, central Goliad, southern DeWitt, northern Lavaca, central Fayette, northern Washington, central Grimes, southern Walker, southern San Jacinto, central Polk, northern Tyler, and northern Jasper counties, Texas.

Following the Carrizo retreat, a re-advance of the sea was initiated, accompanied by continued deposition of the downdip transitional beds, and the reworking of the Carrizo sands. The further advance of the sea brought about the deposition of the fine-grained marine Claiborne shales which overlie the Carrizo-Wilcox.

> In places (where no Carrizo is present) sandy shales above the first porous Wilcox sand contain carbonaceous material and other sediments related to Wilcox deposition. They are probably transitional in origin and are not ordinarily more than 50 to 75 feet thick. It is not to be supposed that this contact is the same age updip and downdip, or even along the strike, but its downdip distinctiveness does indicate a fairly rapid transgression of Claiborne seas with little tendency toward oscillation of the strand line (Culbertson, 1940, p. 1916).

Except for minor local breaks, no unconformity has been noted between the Wilcox and the Claiborne.

The Carrizo straddles the Wilcox-Claiborne boundary, so that its classification must be made arbitrarily, based on considerations other than its stratigraphic correlation. Genetically it belongs with the Wilcox; it is the result of a minor incident closing Wilcox history. The erosional break separating it from the Wilcox is considered unimportant. The Claiborne begins with a new advance of the sea.

Production.—The basal transgressive sands of the upper Wilcox formations, or the first Wilcox sands below the Claiborne shales, are ideally suited for petroleum accumulation in Louisiana, and in the middip and downdip phases in Texas, where the sands are overlain by an impervious shale cap. These sands are productive, for example, in north Louisiana at Urania, in central Louisiana at Neale, Eola, and Ville Platte, in coastal Texas at Joe's Lake, Camp Eleven, Fred, Segno, Magnolia, and Mercy.

Where the Carrizo and upper Wilcox sands merge, petroleum may have migrated vertically through the Wilcox sands into the Carrizo, making this continental body a possible reservoir. Normally the Carrizo is not considered a prolific producer, but is it considered favorable where it is genetically associated with marine source beds either laterally or vertically. In most of Texas, except possibly in the southwestern embayment, the downdip extent of the formation is not great enough to be associated with such marine source beds.

SUMMARY AND CONCLUSIONS

The lowest Wilcox marine and deltaic facies, resting conformably on the Midway, were deposited in a retreating Midway sea. This part of the Wilcox group is least favorable for accumulation of petroleum. During the middle Wilcox, represented on the surface by continental material and in the subsurface by interfingered deltaic, marine, and continental members, very extensive retreat of the sea took place. The alternation of sands and shales produced by the oscillating shoreline are ideal traps for petroleum. In late Wilcox time the sea readvanced. The basal sand deposited during the transgression contains abundant petroleum resources. Under special conditions the continental Carrizo may be productive.

As is true for any producing formation, the Wilcox is productive where its its sands (1) possess favorable porosity and permeability, (2) are associated with marine source beds, and (3) are overlain by sufficiently impervious material to form a trap for petroleum. With a general attitude toward the Wilcox as a "treasury of stratigraphic traps," an approach to the Wilcox problems may be made by the construction of paleogeographic and isopach maps.

Such maps can be expanded to a regional scale, showing the distribution of shales, facies changes from shales to sand or from marine to continental beds, changes in permeability, in carbonaceous or fossil content, as well as sand thicknesses. In this manner, it should be possible to narrow the search for the most favorable types of stratigraphic conditions (Atwill, 1942, p. 161).

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POWELL'S LAKE OIL FIELD, UNION COUNTY, KENTUCKY[1]

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ABSTRACT

The Powell's Lake oil field is in Sec. 16, Coördinate Q-20, Union County, Kentucky, along the Ohio River. This field was discovered in 1944 by the Gulf Refining Company and is owned and controlled by that company. Previous to the discovery several dry holes with slight oil showings had been drilled in the general vicinity.

The discovery well, the Gulf Refining Company's M. S. Rankin 1, SE. ¼, NE. ¼, NE. ¼ of Sec. 16, Q-20, was drilled in July, 1944. It was drilled to the total depth of 2,281 feet in the Cypress sand, which contained salt water and a trace of oil. The well was plugged back to the Waltersburg sand at 1,811–1,824 feet and completed, August, 1944, initially producing 84 barrels of oil per day.

The two principal producing sands in the field are the Mansfield sand of Pennsylvanian age found at 1,200 feet and the Waltersburg sand of Mississippian age at about 1,810 feet. Twenty-five producing wells have been completed in the field and more than half are dual producers. The field has been developed rather slowly during the past 3 years due to floods and inaccessibility of the area.

Average daily production from the 25 producing wells in the field for March, 1947, was 755 barrels of oil. Cumulative production of the field to April 1, 1947, was 489,865 barrels of oil.

The limits of the field now appear to be fairly well defined. A normal fault, downthrown on the west with 250–300 feet displacement, delimits the west side of the field.

The Powell's Lake field represents a combination structural and stratigraphic type of oil field. Moderate structural uplift of the immediate area and differential settling of the sedimentary rocks overlying the Waltersburg sand have produced a slight doming and structural flattening of the strata overlying the field. The Waltersburg sand is of a blanket type, with good development of sand in the upper part of the section. The Mansfield sand is lenticular with a rather flat base and is irregularly convex on the upper surface.

INTRODUCTION

The Powell's Lake field is in Sec. 16, Coördinate Q-20, Union County, Kentucky. It is situated along the Ohio River on flat farm land, about 5 miles north of Uniontown, Kentucky, and 5 miles south of Mt. Vernon, Indiana. Figure 1 shows the geographic location of this field and other fields in the region. The field consists of 25 producing oil wells owned and controlled by the Gulf Refining Company.

The discovery well, the Gulf Refining Company's M. S. Rankin 1, SE. ¼, NE. ¼, NE. ¼ of Sec. 16, Q-20, was drilled in July, 1944. It was drilled to the total depth of 2,281 feet in the Cypress sand, which contained salt water and a trace of oil. The well was plugged back to the Waltersburg sand and completed, August, 1944, initially producing 84 barrels of oil per day.

RÉSUMÉ OF EXPLORATION BEFORE DISCOVERY

Previous to the discovery of the field, three dry holes were drilled in the vicinity by other operators. These holes are about ¾ mile to 1¼ miles southeast and northeast of the discovery well.

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[2] Geologist, Gulf Refining Company. The writer expresses his appreciation to the Gulf Refining Company for permission to publish this paper. Helpful constructive criticism has been given by R. S. Knappen, P. H. Reisher, and C. W. Honess of the Gulf companies. J. O. Lewis of Evansville, Indiana, assisted in drafting some of the figures.

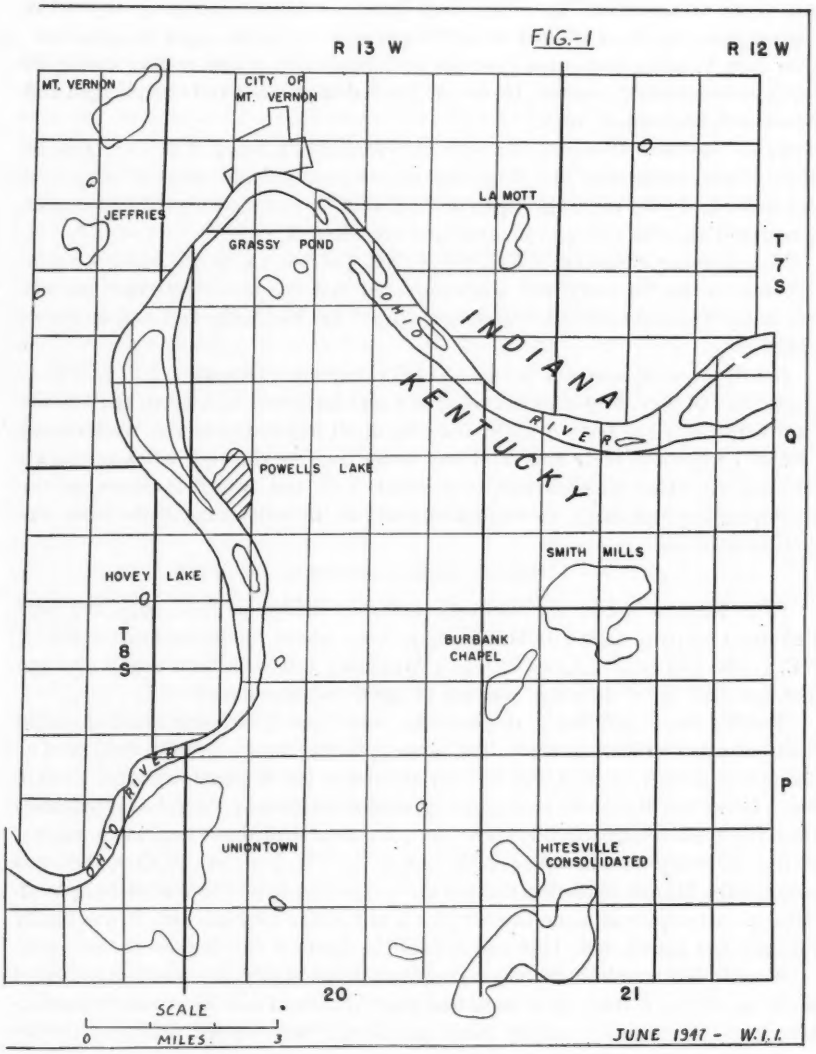

FIG. 1.—Index map showing location of Powell's Lake field and other fields.

The first of these tests was the J. Minton *et al.* Ben Rash 1, at center of south line, SW. ¼, NW. ¼, SW. ¼ of Sec. 13, Q-20, or about 1¼ miles northeast of the discovery well. This well was drilled as a McClosky test, March, 1941, to the

total depth of 2,770 feet. No oil showings were found excepting in the top of the Cypress sand, which contained oil and water in a core from 2,314 to 2,324 feet. Later Sam Yingling *et al.* took over the well, reworking it and setting casing on the Cypress sand at 2,294 feet. However, it failed to produce and was plugged and abandoned, September, 1942.

N. V. Duncan's Deacon 1 in center of NW. ¼, SE. ¼, SE. ¼ of Sec. 17, Q-20, or about ¾ mile southeast of the discovery well, was completed, August, 1941, as a McClosky test with the total depth of 2,756 feet. No oil showings of importance were found and the well was plugged and abandoned.

N. V. Duncan's Sneed 1, NW. ¼, SW. ¼, NE. ¼ of Sec. 14, Q-20, or about a mile northeast of the discovery well, was completed with the total depth of 2,766 feet and plugged and abandoned, December, 1941. This McClosky test had no showings of oil.

Nearly 2 years later, the Kingwood Oil Company's Deacon 1, SE. ¼, NE. ¼, SE. ¼, SE. ¼ of Sec. 16, Q-20, was drilled as a McClosky test in August, 1943, to the total depth of 2,728 feet. A slight showing of oil was found in the Waltersburg sand at 1,839–1,844 feet. This sand was cored, the core showing salt water and a little oil. No other oil showings were found. This test, which is shown on the accompanying pool maps, two locations south of the south edge of the field, was then abandoned.

History of Development

After Rankin No. 1, the discovery well, was drilled in July, 1944, the Gulf Refining Company drilled its Martin Heirs No. 1, about ¾ mile northeast in NE. ¼, NE. ¼, SW. ¼ of Sec. 14, Q-20. It was a McClosky test with total depth of 2,756 feet, but had no oil showings and was plugged and abandoned.

Rankin No. 2 and No. 3, respectively, were then drilled one location northwest and south of Rankin No. 1. The former produces from the Mansfield sand at a depth of about 1,200 feet, but was low and dry in the Waltersburg sand. Rankin No. 3 found the Mansfield horizon shaly, similar to Rankin No. 1, but it produces from the Waltersburg sand. Rankin No. 4 was next drilled one location northeast of the discovery well, in SW. ¼, NW. ¼, NW. ¼, NW. ¼ of Sec. 17, Q-20, but was shaly in the Mansfield section and too low to produce from the Waltersburg sand. After an attempt was made to use it for a salt-water disposal well, it was finally plugged and abandoned. This well defines the limits of the field on the east side.

Rankin No. 5 and No. 6 were then drilled, respectively, one and two locations S. 60° W. of No. 1. Both these wells had good Mansfield and Waltersburg productive sands. Excessively muddy roads and floods then stopped drilling activities until early in the summer of 1945.

In June, 1945, the Gulf Refining Company drilled its Kennard No. 1, an outpost well, in NE. ¼, NE. ¼, SW. ¼ of Sec. 15, Q-20. Small showings of oil were found in Pennsylvanian sands at depths of 1,126–1,140 feet and 1,185–1,200 feet, and a slight showing of oil in the Aux Vases sand at 2,562–2,574 feet. Casing was set on the Pennsylvanian (Mansfield) sand at 1,184 feet, but the well failed to produce

oil and was plugged and abandoned with the total depth of 2,744 feet.

About the same time the Kennard well was drilled, Keating *et al.* drilled their Elliot Heirs No. 1 test on Slim Island in SW. ¼, NE. ¼, NE. ¼ of Sec. 20, Q-19, or about 1 mile west of Rankin No. 1. This test was drilled into the Waltersburg sand with the total depth of 2,135 feet and was dry in all formations and abandoned. Furthermore, it is on the downthrown side of a normal fault, with approximately 300 feet displacement (downthrown on the west). The position of this fault is shown in Figures 3–6 and is further defined by wells both north and south, which are not shown on the field maps.

During the remainder of 1945, the Gulf drilled Rankin Nos. 7–17, inclusive. Most of these wells were dual producers. Drilling operations stopped in the field early in January, 1946, and were not resumed until April of that year on account of bad roads and floods. Rankin No. 17 was finally cased and completed in April, 1946.

During the remainder of 1946, the Gulf drilled Rankin Nos. 18–27, inclusive. Reference to Figures 3, 4, and 6 shows that wells 24, 25, and 27 at the north end of the field produce from the Mansfield sand, but that in each of them the Waltersburg sand had shaled out. Rankin No. 26 is a dry hole and defines the limits of the field on the northwest side. The additional wells at the south end of the field all produce from the Waltersburg sand, but the Mansfield sand shaled out rather abruptly and is non-productive in these wells. Rankin 21 and 22 produced a small amount of oil from the Palestine sand in addition to the Waltersburg producing sand.

STRATIGRAPHY

Figure 2 is a composite Schlumberger log, which shows the typical stratigraphy in the area. The section from the top down to the lower Menard limestone is taken from Rankin No. 9, that from the lower Menard limestone down to the Barlow limestone from Rankin 1, and that from the Barlow limestone to bottom, from the Gulf Refining Company's Kennard 1.

The writer examined the samples and otherwise performed the geologic service on most of the wells drilled in this field. The lithologic ocharacter of the various strata penetrated by the drill is shown graphically in Figure 2.

RECENT

The area is covered with 50–100 feet of Ohio River alluvium, underlain by beds of Pennsylvanian age. The surface elevations in the area do not vary more than about 20 feet, and no outcrops of bedrock are present.

PENNSYLVANIAN

Pennsylvanian beds of Conemaugh, Allegheny, and Pottsville age occur in in the area from the base of the recent sediments to a depth of about 1,400 feet. These beds consist mostly of gray shales, sandy shales, sands, minor amounts of sideritic material, several coal beds, and a few thin limestones.

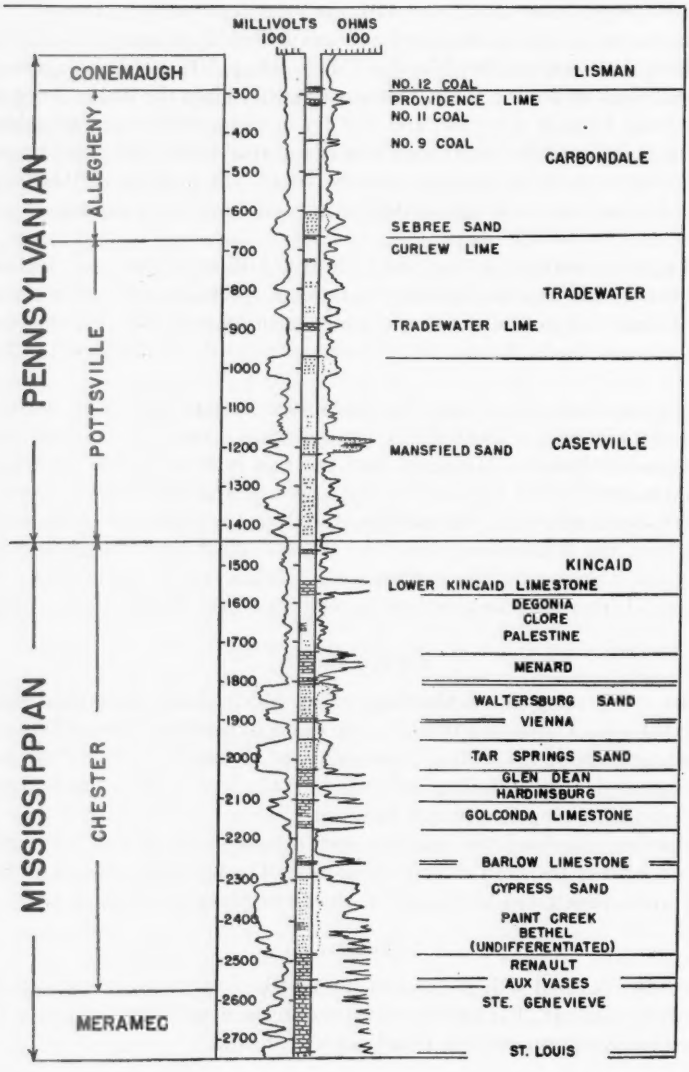

FIG. 2.—Columnar section based on sample studies and Schlumberger logs.

After referring to the published reports, and correlating with other areas of Kentucky, the writer places the base of the Conemaugh group at the base of a thin coal (No. 12), which occurs immediately above the Providence limestone and

at depths of about 300 feet. This lower part of the Conemaugh group consists of the lower Lisman formation and is mostly gray micaceous sandy shale.

The Allegheny group of sedimentary rocks consists of the Carbondale formation, which extends from the top of the Providence limestone to the top of the Curlew limestone at a depth of about 700 feet. Inasmuch as the Curlew limestone is thin and lenticular in this area, the base of the Allegheny group is not readily recognized in all wells.

The Providence limestone, the top of which occurs at a depth of about 300 feet, is the first good marker penetrated by the drill. It consists of light to dark gray, fine crystalline limestone, characterized by abundant *Fusulina*, and with some interbedded gray calcareous shale. It has an average total thickness of about 25 feet.

No. 9 coal is a good consistent marker found at depths of about 425 feet. It varies from 3 to 5 feet thick and is characterized by a prominent anomaly easily identified on the Schlumberger log.

The Sebree sand, which is found at the base of the Carbondale formation, averages about 50 feet in thickness and is fine- to medium-grained, white porous sand.

The Pottsville group of strata includes approximately the lower 700 feet of Pennsylvanian beds and extends from the Curlew limestone at about 700 feet to the top of the Mississippian beds at about 1,400 feet. The Tradewater formation comprises the upper part of the Pottsville group and is about 300 feet thick. This formation consists of interbedded gray shale, micaceous sandy shale, fine-grained sands, a few thin limestones, thin coals, and some sideritic material. The Curlew limestone is in the upper part of this formation and consists of one or two thin lenticular members. The Tradewater limestone occurs at a depth of about 900 feet and is more consistent than the Curlew limestone. It averages about 10 feet in thickness, is crystalline and brown.

The top of the Caseyville formation is tentatively placed at the top of a rather consistent sand occurring at a depth of about 980 feet. The Caseyville formation which is 400–450 feet thick, is more sandy than the Tradewater formation.

The lenticular Mansfield oil sand, where present, is at depths of about 1,200 feet.

The lower part of the Caseyville is characterized by thick, medium-grained white sands, 100–150 feet in thickness and containing salt water.

A pronounced unconformity occurs at the base of the Pennsylvanian series. Either black shale or micaceous sandstone of Pottsville age rests on the Kincaid formation of Chester age.

MISSISSIPPIAN

CHESTER

Kincaid formation.—The Kincaid formation is encountered at 1,400–1,450 feet and is about 150 feet thick. It consists of an upper mottled gray limestone,

below which are 75–100 feet of gray, green, and red shale, siltstone, and shaly sandstone, and at the base a gray to tan crystalline limestone. The upper limestone has a total thickness of 10–15 feet, but is not a good marker and does not show clearly on the Schlumberger log. The lower Kincaid limestone shows high resistance on the Schlumberger log and is a good marker. It has an average thickness of about 25 feet.

Undifferentiated Degonia-Clore-Palestine formations.—Immediately below the Kincaid formation are found in descending order the Degonia, Clore, and Palestine formations, with a total thickness of approximately 140 feet. These beds consist mostly of gray shale with some interbedded thin argillaceous limestones and siltstones. The upper third is considered equivalent to the Degonia formation which, at its type locality and at some other places, consists mostly of fine- to medium-grained, white to gray sandstone, but here is mostly shale with a little siltstone. The middle third contains an increasing amount of thin argillaceous limestone and is equivalent to the Clore formation.

The lower third of this section is the Palestine formation. At its type locality it consists mostly of calcareous, light gray, fine-grained sandstone. In this area, though, it is gray shale with only a trace of sand or siltstone. An exception to this is found in a few wells at the extreme southwest end of the field where the Palestine sand is developed.

Menard formation.—The Menard formation has an average thickness of approximately 80 feet. The upper part consists of one or two thin limestones with intervening gray shale. Below this is the "Massive" Menard, which consists mostly of limestone, but with a shale break in the middle. Beneath the Massive Menard limestone is 10–15 feet of shale, with the "lower Menard" limestone, which is 5–8 feet thick, at the base of the formation. The Menard limestones are rather variable in character, ranging from fine- to coarse-grained and more or less argillaceous. They vary from buff to brown or grayish brown. Chert is irregularly present in some of the beds. The lower part of the Massive limestone is characterized by dolomitic limestone. The interbedded shales in the formation are mostly medium to dark gray.

Waltersburg formation.—The Waltersburg formation is about 100 feet thick in the Powell's Lake field and consists mainly of sandstone. Immediately below the lower Menard limestone is 3–4 feet of hard quartzitic sandstone. This member is present in a few of the wells but absent in others. Below this member is commonly found 10–20 feet of gray shale. However, at the extreme south end of the field in wells 21 and 22, porous sandstone has developed in this interval.

The "Main" Waltersburg sand underlies the upper Waltersburg shale and has a maximum thickness of about 80 feet. This sandstone is one of the principal oil reservoirs.

Vienna limestone.—Only two wells of the field have penetrated the Vienna limestone or below. The Vienna limestone is at a depth of about 1,900 feet and is 5–6 feet thick. It consists of grayish brown, medium-crystalline limestone.

Tar Springs formation.—The Tar Springs formation has a total thickness of about 120 feet. The upper 30–50 feet is predominantly gray shale with minor amounts of fine, tightly cemented sand. The lower 70–90 feet consists of fine- to medium-grained gray and white sandstone. The upper few feet of this member is commonly hard and quartzitic, but the bulk of it is porous sand containing salt water.

Glen Dean formation.—The Glen Dean formation has a thickness of about 40 feet. It consists of a thin upper limestone member underlain by a few feet of calcareous or sandy shale, and of a massive, thick lower limestone member. The limestone is typically coarse-grained, crinoidal, and locally contains variable amounts of dolomite and a small amount of chert. It is a speckled brownish gray.

Hardinsburg formation.—The Hardinsburg formation has a thickness of 40–50 feet and consists of greenish gray siltstone, gray shale, and some thin-bedded sandstone. The sandstone is more abundant in the lower part of the formation and is greenish gray, somewhat argillaceous, and rather hard and tight.

Golconda formation.—The Golconda formation has an average total thickness of about 150 feet in this area, including the lower Golconda limestone which, according to present terminology, is called "Barlow" limestone. The lithologic character of the Golconda formation is described as follows, from top to bottom. The upper Golconda limestone has a thickness of 65–70 feet. It is variegated brown and gray, medium- to coarse-grained, and in places cherty and dolomitic. It is interbedded with thin layers of gray shale. Below this upper Golconda limestone is 15–30 feet of red, green, and gray shale, which is a very characteristic marker. Beneath this are 40–50 feet of gray shale, gray silty sandstone, and yellow and pink, coarse crinoidal, lenticular limestone, which are equivalent to the Jackson sand farther southeast in Kentucky. The basal Golconda limestone called the Barlow, is one of the best structural markers in the Illinois basin. The Barlow limestone here is 4–8 feet thick, and is hard, coarse crystalline, mottled medium to dark gray with characteristic black splotches.

Cypress-Paint Creek-Bethel formations.—The section from the base of the Barlow limestone to the top of the Renault limestone is occupied in descending order by the Cypress, Paint Creek, and Bethel formations. As may be seen from the columnar section (Fig. 2), the upper 10–25 feet of Cypress consists of gray shale with a little gray siltstone. Beneath this are about 200 feet of sedimentary rocks consisting mostly of sandstone, in this area referred to as Cypress sandstone. Only the uppermost 100 feet or so of sandstone is of Cypress age. This sandstone is gray to white, fine-grained, and porous. Beneath this are about 40 feet of hard gray calcareous sandstone interbedded with some thin zones of gray and red shale and variegated coarse crinoidal limestone, which constitute the Paint Creek formation. The Bethel formation consists of about 50 feet of fine-grained, greenish gray siltstone, and white to gray, porous white sandstone. The upper and lower contacts of the Paint Creek formation here are difficult to determine both from Schlumberger logs and from samples.

Renault-Aux Vases limestones.—These formations have a thickness of 70–80 feet. The Renault formation is composed of a limestone 20–25 feet thick, underlain by 10–15 feet of gray, red, and green shale. The Renault limestone is variegated in nature, varying from fine- to coarse-grained, gray to brown, and containing zones of crinoidal, dolomitic, and oölitic material.

The Aux Vases limestone (called lower Renault by some geologists) is variegated gray, pink, and yellow, crinoidal, and with local zones of oölites and dolomite. It is interbedded with gray, green, and red shale.

Aux Vases sand.—This bed is 10–20 feet thick and consists of greenish gray to reddish, fine-grained, tight shaly and silty sand.

MERAMEC

Ste. Genevieve formation.—The Ste. Genevieve formation consists principally of limestone and has an average thickness of about 170 feet in this area. Elswehere in the Illinois basin it may be divided from top to bottom into the Levias, Rosiclare, and Fredonia members. The upper member (the Levias) typically consists of gray to brown, dense to crystalline limestone, with some locally developed oölitic limestone and thin interbedded gray shale. The Rosiclare member, where developed, is dominantly sandstone with lenses of shale and sandy limestone. Its average thickness in the Illinois basin is probably 25–30 feet. The Fredonia member is by far the thickest and is composed of beds of fine-grained, gray and brown limestone, dolomites, dolomitic limestones and locally developed beds of oölitic limestone. The McClosky oil-producing zones in the Fredonia member are porous oölitic limestones with more or less crystalline calcite in the interstices. In the Powell's Lake field and adjacent area, no attempt has been made to subdivide the Ste. Genevieve into the various members.

St. Louis formation.—The St. Louis formation is composed chiefly of fine-grained dolomitic and cherty limestones, gray to brown, and with some oölitic, argillaceous, and sandy beds.

STRUCTURE

Surface structure.—Powell's Lake field and the surrounding area lie along the Ohio River flats, with surface elevations varying from 340 to 360 feet above sea-level. This area is covered with alluvium and no outcrops are present.

Shallow subsurface structure.—The highest marker beds encountered are the Providence limestone, at depths of about 300 feet, and No. 9 coal about 100 feet deeper. The structure on top of the Providence limestone shows a flattening or terracing over the field, with the Rankin wells 10, 14, and 18 slightly higher structurally than the other wells in the field. The structure on No. 9 coal is somewhat similar.

SUBSURFACE STRUCTURE

Regional structure.—Regionally, this area is on the southeast flank of the Illinois basin. The regional dip on the subsurface beds varies from 20 to 40 feet per mile northwest to the bottom of the Illinois basin, which lies about 30 miles

northwest of Powell's Lake field in eastern Wayne County and western Edwards County, Illinois. The regional dip of the various formations increases with depth, being greater for Mississippian beds than those of Pennsylvanian age. There is a widespread major unconformity at the base of the Pennsylvanian sediments, and possibly other minor disconformities between some of the formations.

Local structure.—The subsurface structure of Powell's Lake field is shown by the accompanying structural maps and isopach map (Figs. 3–6).

The structure on top of the Mansfield sand is shown in Figure 3. This map represents the top of the Mansfield sand lens, which is elongate N. 20° E. The highest structural point (−822 feet) occurs in Rankin No. 17 near the southwest edge of the field.

Figure 4 is an isopachous map of the Mansfield sand and shows the general shape of this lens. The wells with the thickest Mansfield sand are normally structurally high on the sand. The Mansfield sand lens is nearly flat on the base and irregularly convex on the upper surface. It shales out rather abruptly.

The structure of the field contoured on top of the lower Menard limestone is shown in Figure 5. This map shows the field on a slight dome. The contours, if projected and closed on the southwest side (as is probably the fact), show the long axis of the structure trending northeast and southwest with about 20 feet of closure.

The structure of the top of the Waltersburg sand is shown in Figure 6. This map also shows the field on a low dome, corresponding in general with structure of the lower Menard limestone. This structural condition was probably caused by a combination of slight local arching followed by differential settling of the upper formations deposited over the sand body.

Detailed structural information concerning formations lower than the Waltersburg sand is not available for the Powell's Lake field. The Gulf Refining Company's Rankin 1 was the only well in the field penetrating below the Waltersburg sand, with the exception of Rankin No. 2, which was drilled to the Vienna limestone. However, the Barlow limestone was encountered at −1912 feet in Rankin No. 1, which when compared with the surrounding wildcat wells, indicates a structural flattening with a slight closure. The Cypress sand was encountered at −1917 feet or immediately below the Barlow limestone in this well. This sand contained salt water, with only a slight showing of oil. Comparison of this sand top with surrounding wildcat wells shows the top of the Cypress sand structurally high in Rankin No. 1, forming a dome with approximately 25 feet of closure. This doming is believed to be due more to sedimentation than to structure, because of the thickening of the Cypress shale interval between the Barlow limestone and Cypress sand in the surrounding wells.

Faults.—A definite normal fault lies west of the field, striking about N. 20° E. as shown on the maps. This fault is downthrown on the west and passes between Powell's Lake field and the Keating *et al.* Elliot Heirs No. 1 dry hole, on Slim Island. This hole is on the downthrown side of the fault on all formations, which

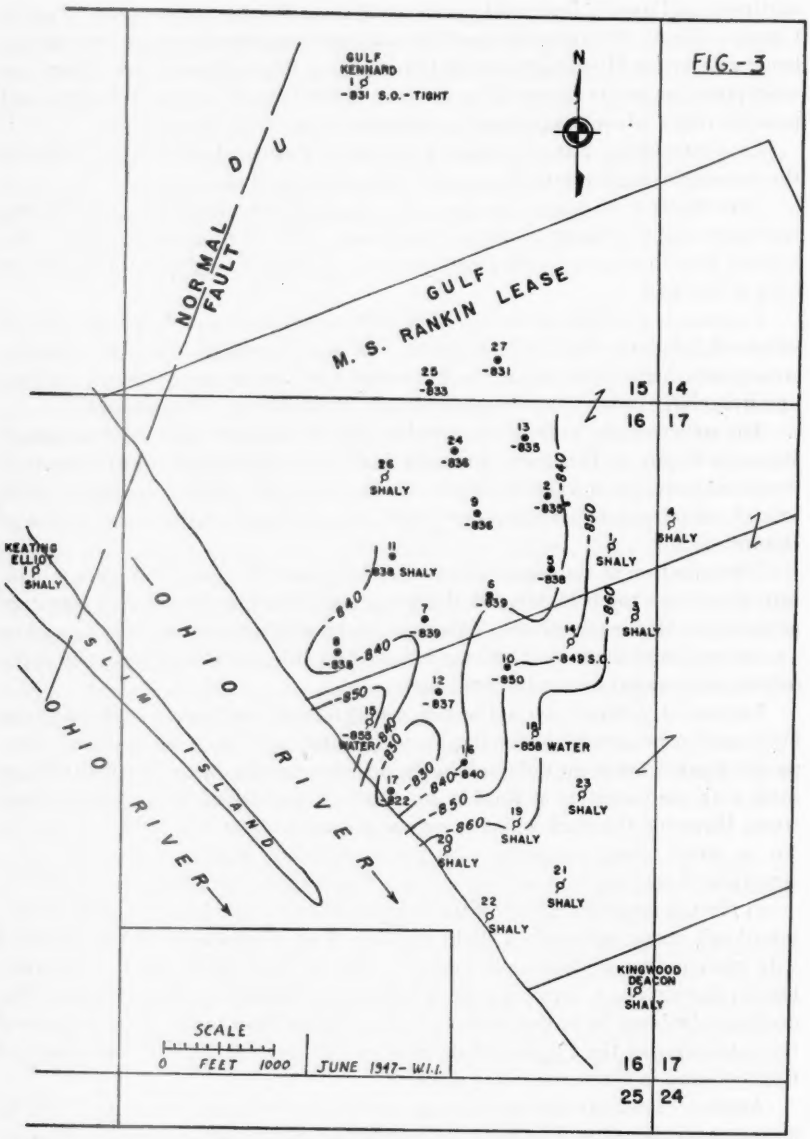

FIG. 3.—Structure on top of Mansfield sand, Powell's Lake field, Sec. 16, Quadrangle Q-20, Union County, Kentucky.

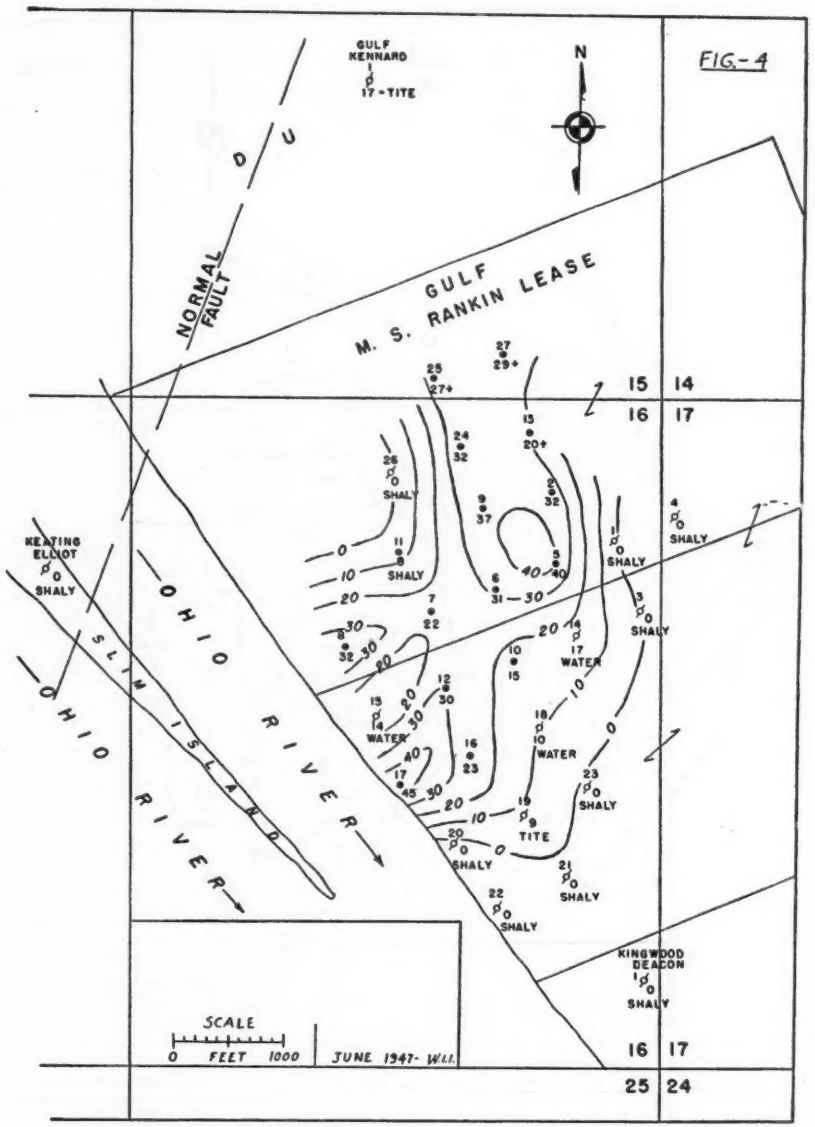

FIG. 4.—Isopachous map of Mansfield sand, Powell's Lake field.

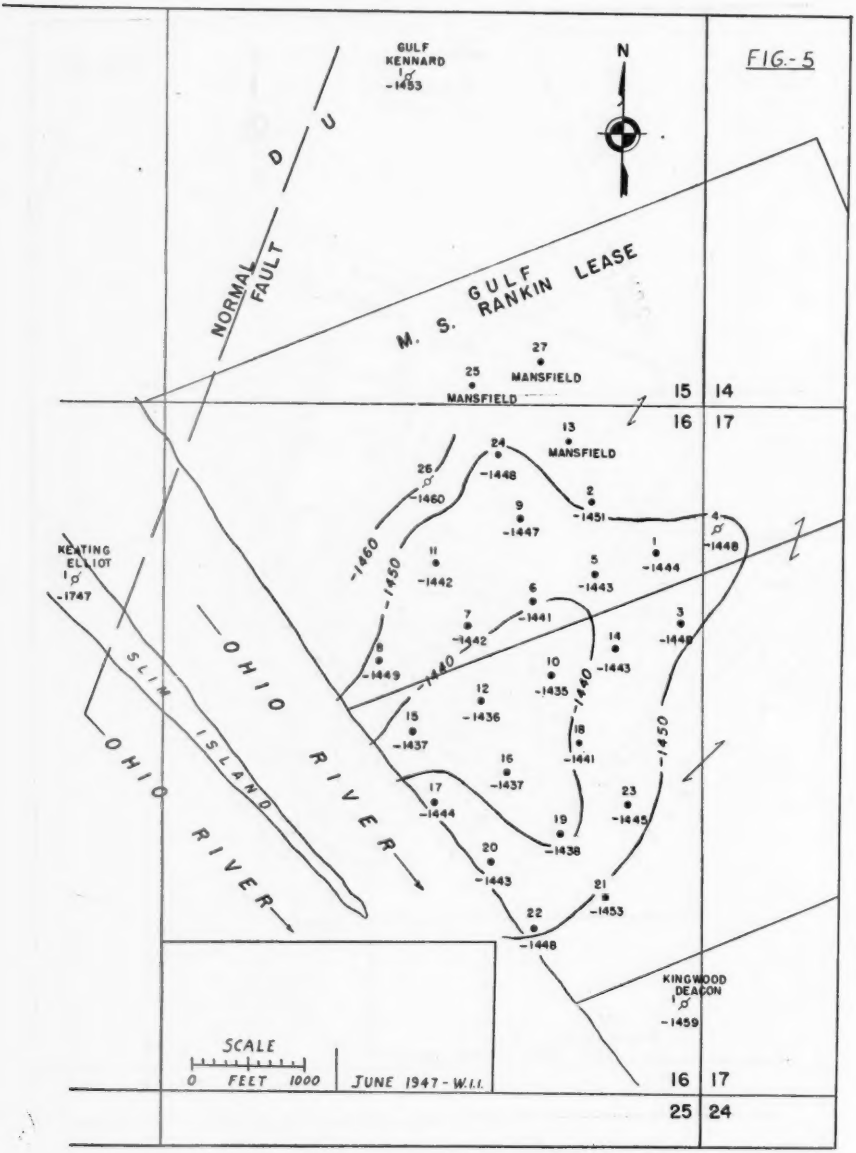

FIG. 5.—Structure on top of lower Menard limestone, Powell's Lake field.

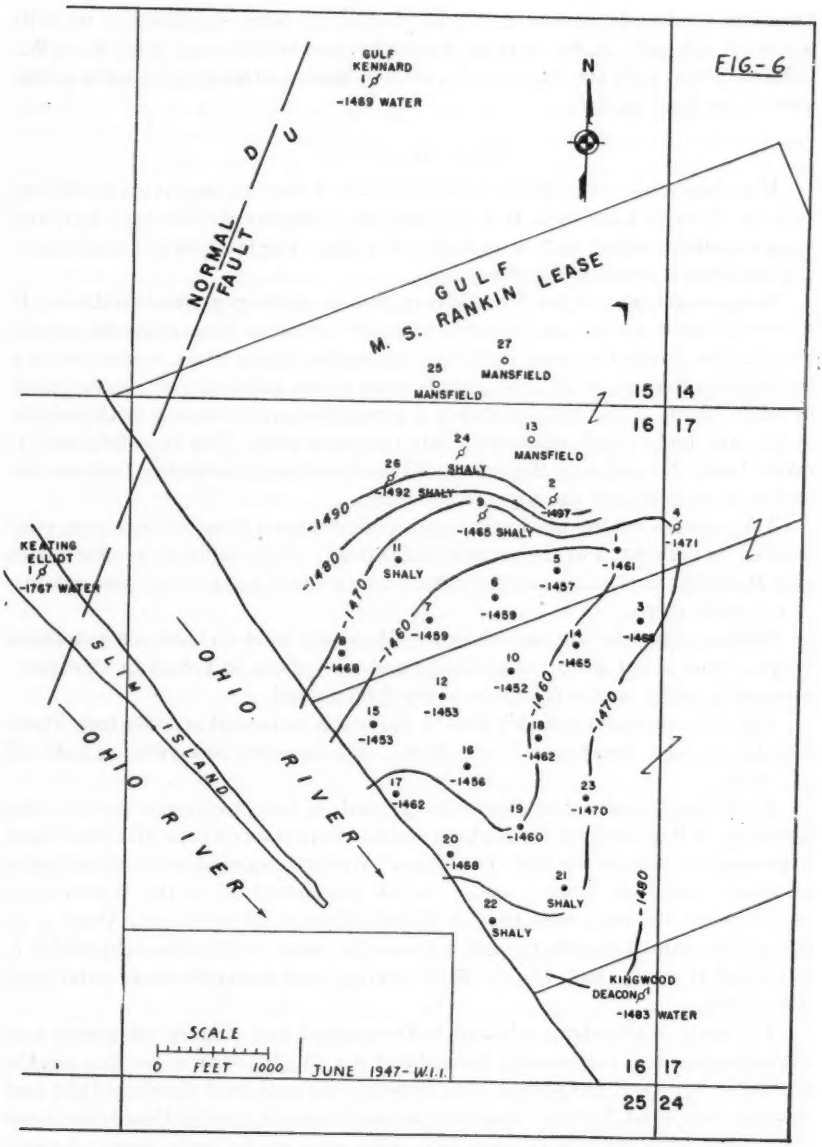

FIG. 6.—Structure on top of main Waltersburg sand, Powell's Lake field.

has about 300 feet displacement. The position of this fault is established by wells which cut the fault, in Sec. 4, Q-20, Kentucky, and in Sec. 12, T. 8 S., R. 14 W., Indiana. These wells are, respectively, about 3 miles northeast and 3 miles southwest of the Keating well.

Productive Sands

Mansfield sand.—The Mansfield sand is one of the two important producing zones in Powell's Lake field. It is encountered at depths of 1180–1200 feet, and has a thickness ranging up to a maximum of 45 feet. The position and thickness of this sand lens is shown in Figures 3 and 4.

Samples and cores of the Mansfield are fine- to medium-grained sandstone. It is brown, friable, porous, and characteristically somewhat micaceous and carbonaceous. The productive sand contains interbedded sandy shale, varying from a few layers a fraction of an inch thick in some of the wells, to 3 or 4 inches thick in others. Some of the wells contain 3–4 feet of dry sandy shale near the middle of the sand body which separates it into two main parts. The Mansfield sand is rather lenticular and may thicken or thin and shale out completely from one location to another near the edges of the lens.

The porosities of the productive sand, as determined from core analyses, vary from 15–23 per cent, and the permeabilities from 2 to 650 millidarcys. Estimates give Mansfield sand an average porosity of 18.7 per cent and average permeability of 122 millidarcys.

Schlumberger electric logs show the Mansfield sand to have self-potentials varying from about 40 to 120 millivolts and with about 60-120 ohms resistance, depending partly on the condition of the drilling mud.

The oil-water contact of this sand in the field is estimated at −860 feet. There appears to be a transitional zone from −860 to −865 feet yielding both oil and water.

Waltersburg sand.—The Waltersburg sand is the productive sand in the discovery well of the field and is about equal in importance to the Mansfield sand in production of oil in the field. The "main" Waltersburg sand is found at depths of 1,810–1,820 feet. Wells 1 and 2, which penetrated all of the Waltersburg section, show the main sand to have a total thickness of 70–80 feet. About 5–22 feet of the main Waltersburg sand is above the water level in the field, which is estimated at −1,474 feet. The estimated average sand thickness above water level is 11.5 feet.

The main Waltersburg oil sand is fine-grained and slightly micaceous and carbonaceous. It is horizontally bedded and has a light brown color. The sand is ordinarily fairly soft and porous, but commonly contains local streaks of tight and medium-hard sand. It varies from thin-bedded to massive and ordinarily the cores show paper-thin laminae of dark gray micaceous sandy shale. Some of these interbedded layers of sandy shale are an inch or more in thickness.

The Waltersburg section between the lower Menard limestone and top of the main Waltersburg sand is somewhat variable. Immediately below the lower Menard limestone there is ordinarily 3–4 feet of hard tight quartzitic sand. This sand may be white and dry or slightly oil-stained. Below this sandstone is 3–6 feet of dark gray shale or sandy shale, and below that, varying thicknesses of upper Waltersburg sand, which is tight and more or less shaly. The upper Waltersburg sand is 12–15 feet thick in wells 19 and 20, and is porous enough to contain a little oil in productive quantity.

In wells 21 and 22, the porosity is still further developed and these wells produce only from this upper sand, the main sand being structurally too low. In the structurally high part of the field, the upper sand is not developed and production is from the main sand.

Core analyses of the main Waltersburg sand show porosities varying from 14 to 21 per cent, with an average of 18.5 per cent; and permeabilities varying from 1 to 700 millidarcys, with an average of 125 millidarcys.

Schlumberger electric logs show the main Waltersburg sand to have self-potentials of 50–110 millivolts and resistivities of 30–100 ohms.

In general, the Waltersburg sand is less lenticular than the Mansfield sand, is more of a blanket sand and can be more easily predicted ahead of the drill than the Mansfield.

Palestine sand.—Besides the two main producing sands, the Palestine sand contained oil showings in three wells and produced small quantities of oil in two others, all in the south end of the field. In most of the field, including the first 16 wells drilled, the Palestine sand is completely absent. Wells 17, 19, and 20 each had Palestine sand varying from 5 to 8 feet thick, with small non-commercial showings of oil. Wells 21 and 22 each had 20–25 feet of Palestine sand, which produced small amounts of oil together with some water. The Palestine sand in these wells was found at depths of about 1,700 feet. Cores of this sand are rather fine, hard, and tight, and containing some dark shaly sand. The core from the best of these wells (No. 22) showed an average porosity of 18.4 per cent and average permeability of 30 millidarcys.

Drilling and Completion Practice

Drilling practice.—The wells were drilled with medium-sized type of rotary rigs commonly used in the Illinois basin. An average time of about 2 days was used to rig up and drill the surface hole and cement the surface casing. The drilling time from under the surface casing to the Mansfield sand usually varied from 2 to 3 days, and for Waltersburg wells, 5 to 7 days. This includes coring and cementing casing on top of the productive sand. Depths are usually checked either with a Halliburton measuring line or by measuring the drill pipe. Straight-hole surveys are made with the acid bottle every 250 feet. No trouble was found in maintaining straight holes in this field.

The upper part of the holes is drilled with thin natural mud or water. Aquagel is added as the hole is deepened and especially before coring and running a Schlumberger electrical survey.

Samples are caught from the wells every 10 feet from below the surface casing to near bottom or near a coring point. Shortly above an expected oil zone, they are caught every 5 feet or less. Drilling-time records are kept on all the wells, usually with 2-foot drilling time, excepting just above possible oil-producing zones, where 1-foot drilling time is recorded.

The oil zones are cored with Hughes Type J core barrels, with hard formation heads. In addition, drill-stem tests were made on a few of the wells as an additional check.

Schlumberger survey.—A Schlumberger survey is made on all the wells after they have been drilled to bottom.

Casing and cementing.—Common practice is to drill an 11- or 12½-inch surface hole to a depth of 100–150 feet, and cement either 8⅝-inch or 10¾-inch surface casing, with about 200 sacks of quick-setting cement. After allowing cement to set for 24 hours, a 7⅞- or 7⅞-inch hole is drilled ahead. The oil zones are cored, after which the hole is reamed and drilled to bottom.

After running the Schlumberger survey, new 5½-inch casing is set on top of the lowest productive sand and cemented by Halliburton process with about 300–500 sacks of cement. If there is more than one productive zone, securaloy casing is set opposite the upper oil sand.

Completion practice.—After allowing cement to set 2 or 3 days, a spudder is moved to the location, the drilling mud bailed out, the plugs drilled, and the hole is cleaned out. The well is then swabbed for a few hours or a day or two to test initial production and it may be deepened a few feet. A small shot of 10–40 quarts of nitro-glycerine is detonated opposite the lowest oil sand and the hole is again cleaned out and swabbed. If the well also has an upper productive sand (principally the Mansfield sand), securaloy is removed with caustic or is perforated and this zone tested. On most of the wells a pumping unit is installed and the well is pumped for some time before the securaloy is removed from the upper zone.

PRODUCTION

Twenty-five producing oil wells and two edge dry holes have been drilled in the Powell's Lake field. Of these, six are Mansfield sand producers, eight are Waltersburg sand wells, two are dual Waltersburg and Palestine sand producers, and the remainder (nine) are dual Waltersburg and Mansfield sand producers.

Initial productions of the Mansfield wells vary from 65 to 240 barrles of oil per day; those of the Waltersburg wells vary from about 70 to 190 barrels per day; and the dual Waltersburg and Mansfield wells range up to 340 barrels per day. The production from the two dual Waltersburg and Palestine wells was mainly from the Waltersburg sand.

Little or no water was produced from these wells when first completed, but

there was a gradual encroachment of water so that within a year most of the wells were producing 5–25 per cent water.

Guage figures for October 1, 1946, show a daily production of 944 barrels of oil from 24 producing wells in the field.

Average daily production from the 25 producing wells in the field for March, 1947, was 755 barrels of oil. Cumulative production for the field to April 1, 1947, was 489,865 barrels of oil. A little more than half of this production is estimated to be from the Mansfield sand and a little less than half from the Waltersburg sand, with negligible amounts from the Palestine sand.

A few of the wells produced an appreciable amount of gas which was sufficient to operate some of the pumping units in the field.

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ELK BASIN, ANTICLINE, PARK COUNTY, WYOMING, AND CARBON COUNTY, MONTANA[1]

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ABSTRACT

The Elk Basin anticline is in the north end of the Big Horn Basin on the Wyoming-Montana line and is approximately 25 miles east of the Beartooth Mountains and the same distance west of the Pryor Mountains. It is a northwest-southeast-trending asymmetrical anticline approximately 8 miles long and 4 miles wide with approximately 5,000 feet of closure.

The crest of the structure is a topographic basin and the oldest formation exposed on the crest of the structure is the Niobrara shale of the Colorado group of Upper Cretaceous age. A complete section from the Fort Union Paleocene through Lance, Lennep, Bearpaw, Judith River, Claggett, Eagle, and Telegraph Creek formations of the Montana group of Upper Cretaceous age to the Niobrara shale of the Upper Colorado group is exposed on the flanks of the structure.

The crest of the structure is cut by numerous normal transverse and several normal longitudinal faults. The south end of the structure is cut by a northeast-southwest-trending thrust fault with a throw of approximately 3,100 feet.

The Elk Basin field was discovered in 1915 by a well completed in the First Frontier sand (Upper Cretaceous) which produced 50 barrels of oil per day. In 1922 gas was discovered in the Dakota sandstone (Lower Cretaceous). Tensleep (Pennsylvanian) production was discovered in 1942 and 129 wells have been drilled and completed as producers in the Tensleep formation. In 1946 the discovery well in the Madison formation (Mississippian) was completed, flowing approximately 200 barrels of oil per day.

The Elk Basin field is a unitized operation with the Stanolind Oil and Gas Company as unit operator of the Embar-Tensleep unit.

INTRODUCTION

The surface geology described in this paper is largely compiled from the work of other geologists, especially the work of E. L. Estabrook,[3] H. T. Morley, J. G. Bartram,[4] and, more recently, the work of C. E. Dobbin.[5]

LOCATION

The Elk Basin anticline (Fig. 1) is in Ts. 57 and 58 N., Rs. 99 and 100 W., Park County, Wyoming, and in T. 9 S., R. 23 E., Carbon County, Montana, in the north end of the Big Horn Basin, approximately equi-distant between the Beartooth Mountains on the west and the Pryor Mountains on the east.

[1] Read before the Association at Los Angeles, March 27, 1947. Manuscript received, May 23, 1947. Published by permission of the Stanolind Oil and Gas Company.

[2] Division geologist, Stanolind Oil and Gas Company. The writer acknowledges the assistance of Charles C. Bajza and M. D. Hubley in the preparation of illustrations and in offering helpful suggestions and criticism.

[3] E. L. Estabrook, "Faulting in Wyoming Oil Fields," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 2 (March-April, 1923), p. 95.

[4] J. G. Bartram, "Elk Basin Oil and Gas Field, Park County, Wyoming, and Carbon County, Montana," *Structure of Typical American Oil Fields*, Vol. II, Amer. Assoc. Petrol. Geol. (1929), pp. 577–88.

[5] C. E. Dobbin, "Geologic and Structure Map of the Elk Basin Oil and Gas Field and Vicinity, Park County, Wyoming, and Carbon County, Montana," *U. S. Geol. Survey* (1944).

HISTORY OF EXPLORATION AND DISCOVERY

The Elk Basin anticline was located and discussed in several coal reports of the United States Geological Survey.[6] The discovery well of the Elk Basin field was located on surface geology in the NW. ¼, NW. ¼ of Sec. 30, T. 58 N., R. 99 W., Park County, Wyoming, and was successfully completed in October, 1915, by Jim Hurst *et al.*, as an oil well in the First Wall Creek sand of the Frontier forma-

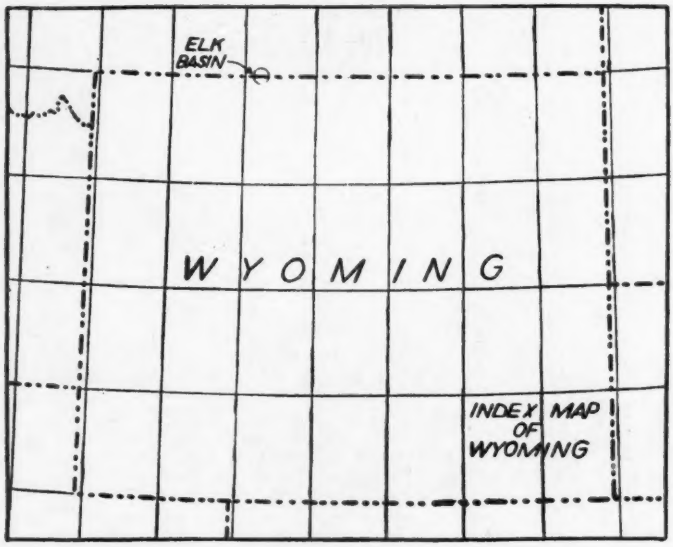


FIG. 1.—Index map of Wyoming showing location of Elk Basin field in northwestern Wyoming. Average west-east length of state is 350 miles.

tion of Upper Cretaceous age.[7] Hurst *et al.* later organized the Elk Basin Petroleum Company which merged with the Mutual Oil Company. The Mutual Oil Company was later acquired by the Continental Oil Company.

TOPOGRAPHY

The structural crest of the Elk Basin field (Fig. 2) is a topographic basin, or

[6] C. A. Fisher, "Coal of the Big Horn Basin in Northwestern Wyoming," *U. S. Geol. Survey Bull. 225* (1904), pp. 345–64.
C. A. Fisher, "Development of the Bear Creek Coal Fields, Montana," *ibid., Bull. 285* (1906), pp. 269–70.
C. W. Washburne, "Coal Fields of the Northeast Side of the Big-Horn Basin, Wyoming, and of Bridger, Montana," *ibid., Bull. 341* (1909), pp. 165–99.

[7] J. G. Bartram, *op. cit.*

FIG. 2.—Aerial photograph of Elk Basin field, reproduced by permission of Aero Exploration Company, Tulsa, Oklahoma. Symbols: Tfu, Fort Union; Kl, Lance; Kls, Lennep sandstone; Kbp, Bearpaw shale; Kjr, Judith River; Kc, Claggett; Ke, Eagle; Ktc, Telegraph Creek; Knc, Niobrara and Carlile shales.

park, surrounded by sandstone hills, and the total relief is approximately 500 feet. The park is eroded out of the soft Niobrara shales, and the sandstone hills are formed by the sandstone members of the Telegraph Creek, Eagle, and Claggett formations of Upper Cretaceous age.

PALEOCENE SERIES

Fort Union formation.—The Fort Union (Fig. 3) on the flanks of the Elk Basin fold consists of approximately 2,500 feet of gray, fine- to medium-grained, loosely bonded sandstone, alternating with gray shale. Locally, coals are developed in the Fort Union.

UPPER CRETACEOUS SERIES

Lance formation.—The Lance formation crops out on the flanks of the Elk Basin field and is composed of buff and gray, fine- to medium-grained, argillaceous sandstones and gray shale with carbonaceous streaks, and has a thickness of 1,040 feet.

MONTANA GROUP

All of the formations of the Montana group crop out on the flanks of the Elk Basin field.

Lennep formation.—The Lennep formation consists of gray, medium-grained sandstone, gray sandy shale, and is 275 feet thick at the outcrop.

Bearpaw formation.—The Bearpaw formation is 115 feet thick, and is gray, silty shale.

Judith River formation.—The Judith River formation has a thickness of 890 feet, and consists of fine- to medium-grained, gray, argillaceous sandstone and gray shale.

Claggett formation.—The upper member of the Claggett is known as the Parkman sandstone. It is approximately 420 feet thick, and consists of gray sandstone alternating with gray shales. The lower 180 feet of the Claggett formation is gray shale, bentonitic at the base.

Eagle formation.—The Eagle sandstone is approximately 200 feet thick and the upper part consists of gray sandstones alternating with gray shales, and contains a locally well developed coal. The basal member of the Eagle sandstone is known as the Virgelle sandstone member, and is approximately 80 feet thick, consisting of light-colored massive sandstone.

Telegraph Creek formation.—The Telegraph Creek formation is approximately 215 feet thick and all excepting the basal 65 feet is sandy shale. The basal member is known as the Elk Basin sandstone, which is 65 feet thick, and is a loosely bonded, massive sandstone.

COLORADO GROUP

Niobrara and Carlile formations.—The Niobrara and Carlile formations have a total thickness of 1,575 feet, and are light gray, silty, slightly calcareous, bento-

FIG. 3

SYST.	SERIES	GROUP	ELK BASIN FORMATION	ELK BASIN MEMBER	ELK BASIN THICKNESS	OREGON BASIN FORMATION	OREGON BASIN MEMBER	OREGON BASIN THICKNESS
TERT.	PALEO.		FORT UNION		2500+			
CRETACEOUS	U. CRET.		LANCE		1040	LANCE		1,050
		MONT.	LENNEP		275	MEETEETSE		1050
			BEARPAW		115			
			JUDITH RIVER		890	MESAVERDE		1300
			CLAGGETT	PARKMAN S.S.	590			
			EAGLE	VIRGELLE	200	CODY SH.		3000
			TELEGRAPH CR.	ELK BASIN	215			
		COLO.	NIOBRARA-CARLILE		1575			
			FRONTIER		450	FRONTIER		500
			MOWRY-	MUDDY ZONE	990	MOWRY-	MUDDY ZONE	940
	L. CRET.		THERMOPOLIS	SILTY ZONE		THERMOPOLIS	SILTY ZONE	
			CLOVERLY	GREYBULL 30 FUSON 40 LAKOTA 85	155		DAKOTA 50 FUSON 225 LAKOTA 75	350
JURAS.	U. JUR.		MORRISON		260	MORRISON		250
			SUNDANCE		530	SUNDANCE		480
	MID. JUR.		GYP. SPRG.		40	GYP. SPRG.		30
TRIAS.			CHUGWATER		560	CHUGWATER		805
			DINWOODY		16	DINWOODY		40
PERM.			PHOSPHORIA		30	PHOSPHORIA		160
PENN.			TENSLEEP		200	TENSLEEP		175
			AMSDEN		210	AMSDEN		240
MISS.	L. MISS.		MADISON		798	MADISON		900
DEV.	U. DEV.		THREE FORKS		100	DEVONIAN		105
	MID. DEV.		JEFFERSON		300			
ORD.	U. ORD.		BIG HORN		300	BIG HORN		405
CAMB.	U. CAMB.		GALLATIN		500	GALLATIN		515
	MID. CAMB.		GROS VENTRE		500	GROS VENTRE		480
			FLATHEAD		150	FLATHEAD		186
						GRANITE		

NOTE:

THICKNESSES FOR CODY SH, AND ABOVE OBTAINED FROM PIERCE AND ANDREWS U.S.G.S. BULL. 921B.

THICKNESSES FOR MADISON L.S., AND BELOW OBTAINED FROM PAC. WEST.* 5 CONNAGHAN, 29-5IN-100W, PARK CO., WYO.

THICKNESSES OF MAD. AND LOWER FMNS. IN ELK BASIN ARE ESTIMATED.

FIG. 3.—Columnar section showing stratigraphy of Elk Basin field and correlation of formations between Elk Basin and Oregon Basin fields. Oregon Basin field is in Ts. 50, 51, and 52 N., Rs. 100 and 101 W., Park County, Wyoming.

nitic, and in part glauconitic, shale. The Niobrara occurs in outcrops, and in the subsurface the Niobrara and Carlile are not lithologically differentiated.

Frontier formation.—The Frontier formation is 450 feet thick, and contains two producing zones, the First and Second Wall Creek sandstone members, with intervening gray shale. The First Wall Creek sandstone is poorly developed and is, in reality, only gray sandy shale. The Second Wall Creek sandstone is well developed sandstone 60 feet thick, and is fine-grained, calcareous, light gray, and glauconitic, with abundant dark-colored rainerals which give a salt-and pepper appearance. Porosity is poorly developed in the Second Wall Creek sandstone.

Mowry formation.—The Mowry is approximately 350 feet thick, and is light gray, bentonitic, micaceous, sandy shale.

"Upper" Thermopolis formation. The Thermopolis formation is 640 feet thick, and consists of dark gray, bentonitic, splintery shale with a 10-foot sandstone member in the lower part known as the Muddy sandstone.

LOWER CRETACEOUS SERIES[8]

"Lower" Thermopolis formation.— The basal 60 feet of the Thermopolis shale is silty gray shale, commonly referred to as the Silty zone. The Thermopolis formation, according to present terminology, transgresses the time line between the Lower and Upper Cretaceous, and should be redefined.

Cloverly formation. Greybull sandstone member.—The Greybull sandstone is is approximately 30 feet thick, and consists of massive, white, fine-grained, angular, calcareous, quartzitic sand. Porosity is fairly well developed.

Fuson shale member.—The Fuson shale is 40 feet thick and is composed of variegated red, green, and gray shales.

Lakota sandstone member.—The Lakota sandstone is 85 feet thick and is erratic in its thickness and distribution. The Lakota sandstone is medium-grained, angular, glassy sandstone commonly conglomeratic, with chert pebbles. The Lakota has fair to good porosity.

UPPER JURASSIC SERIES

Morrison formation.—The Morrison is 260 feet thick. It is composed of bentonitic, variegated red, green, purple, and gray shales and contains white angular chert fragments. The lower part of the Morrison is sandy.

Sundance formation.—The upper 90 feet of the Sundance is calcareous, glauconitic, white, fine grained sandstone with poor porosity. Below the upper Sundance sand is a 280-foot middle green and gray shale zone. The shale is soft, glauconitic, and fossiliferous near the base. Below the green shale zone is a 160-foot zone of thin, oölitic to pseudo-oölitic limestone, alternating with green to gray shale.

[8] J. D. Love *et al.*, "Stratigraphic Section sand Thickness Maps of Lower Cretaceous and Nonmarine Jurassic Rocks of Central Wyoming," *U. S. Geol. Survey Prelim. Chart 13*, Oil and Gas Inves. Ser. (September, 1945).

Basin fields. Oregon Basin field is in Ts. 50, 51, and 52 N., Rs. 100 and 101 W., Park County, Wyoming.

FIG. 4

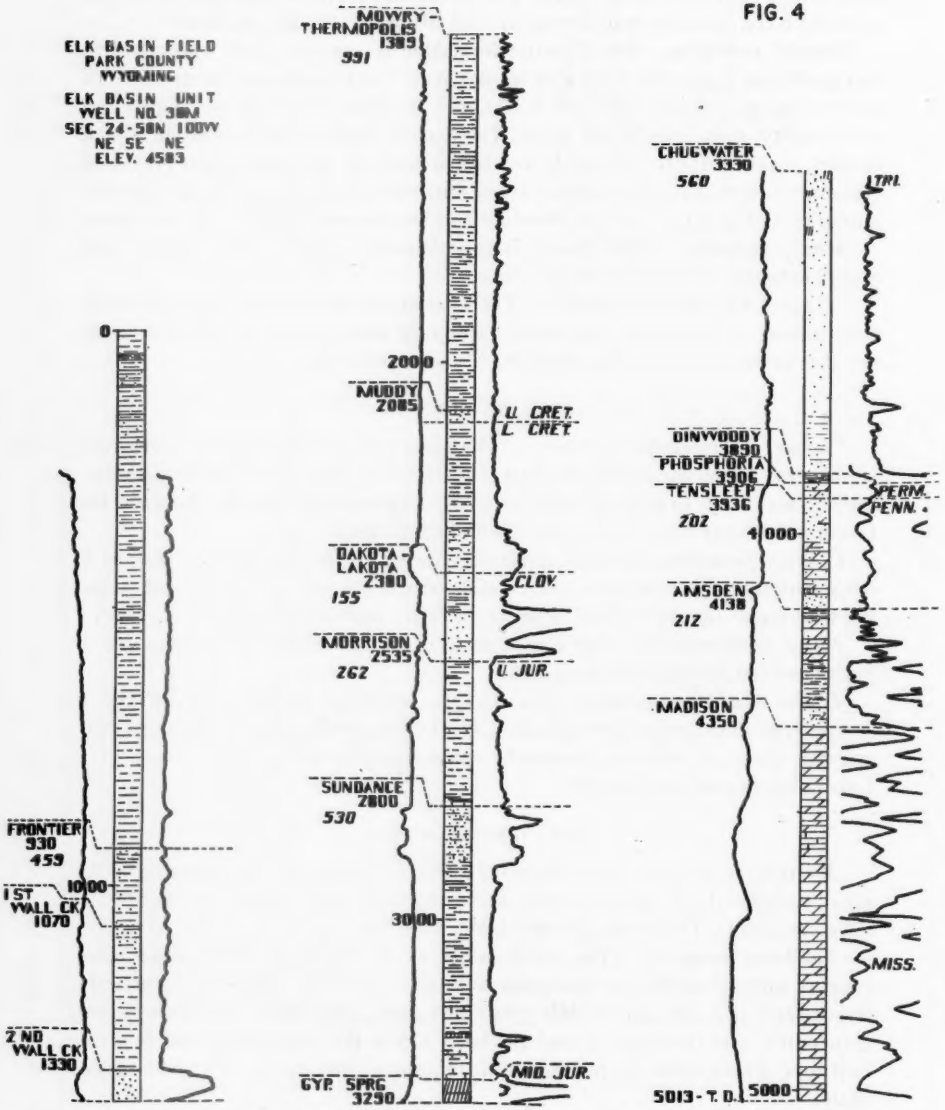


FIG. 4.—Type electric log showing lithologic character and correlation, Stanolind No. 38-M Unit, Madison deep test in Sec. 24, T. 58 N., R. 100 W., Park County, Wyoming, on crest of Elk Basin field.

MIDDLE JURASSIC SERIES[9]

Gypsum Spring formation.— The Gypsum Spring formation is composed of dense crystalline anhydrite and is 40 feet thick. The Gypsum Spring is a key bed that has a wide distribution throughout the Rocky Mountain area.

TRIASSIC SYSTEM

Chugwater formation.—The Chugwater at Elk Basin is 560 feet thick, and is composed of red silty shale and red shaly siltstone.

Dinwoody formation.—The Dinwoody formation is 16 feet thick, and is composed of green and brown shale with anhydrite stringers.

PERMIAN SYSTEM

Phosphoria formation.—The Phosphoria formation is 30 feet thick and is composed of gray dolomite annd gray, fine-grained dolomitic sandstone and sandy dolomite. The porosity in the Phosphoria is poorly developed. The contact between the Phosphoria and the underlying Tensleep appears gradational, although there is a definite time break between the two formations.

PENNSYLVANIAN SYSTEM

Tensleep formation.—The Tensleep formation is 200 feet thick, and consists of fine- to medium-grained, white, quartzitic, friable sandstone with good porosity. Thin dolomite stringers are present throughout the formation, and the sandstone becomes increasingly dolomitic near the base.

Amsden formation.—The Amdsen formation consists of 210 feet of alternating green, red, and purple shale, purple and gray shaly domolite, and white fine-grained sandstone. A basal sandstone of the Amsden is present and has a thickness of 36 feet. The sandstone is gray, dolomitic, fine-grained, and tight, with only traces of porosity.

LOWER MISSISSIPPIAN SERIES

Madison formation.—The Madison at Elk Basin is estimated to be 798 feet thick, of which 663 feet were penetrated in Unit No. 38-M, drilled on the crest of the structure (Fig. 4). The Madison consists principally of gray, finely crystalline dolomite, cherty in part, with two thin zones of white to brown, cherty, crystalline limestone in the upper part of the formation. The poorly to fairly porous zones in the Madison occur only in the dolomite sections which are distributed throughout the 663 feet of section drilled in Unit No. 38-M.

None of the formations below the Madison has been penetrated on the Elk Basin structure, and the section below the Madison is estimated from the occurrence of the lower formations in adjacent areas.

[9] J. D. Love *et al.*, *op. cit.*

UPPER DEVONIAN SERIES

Three Forks formation.—The Three Forks formation consists of gray calcareous shale. Its thickness is estimated as being 100 feet.

MIDDLE DEVONIAN SERIES

Jefferson formation.—The Jefferson formation is estimated to be 300 feet thick and consists of brown crystalline dolomite to brown calcareous dolomite, with a well developed thin zone of fair to good porosity at the base of the formation.

SILURIAN SYSTEM

No Silurian beds have been recognized in the section in this area.

UPPER ORDOVICIAN SERIES

Bighorn formation.—The Bighorn dolomite is estimated to be 300 feet thick and is dense, crystalline dolomite notably lacking in porosity.

UPPER CAMBRIAN SERIES

Gallatin formation. —The Gallatin formation is estimated to be 500 feet thick, and consists of green shales and glauconitic, gray to buff limestone with some glauconitic, fine-grained sandstone, and green fossiliferous shale at the base.

MIDDLE CAMBRIAN SERIES

Gros Ventre formation.—The Gros Ventre formation is estimated to be 500 feet thick and consists of gray, glauconitic limestone, gray glauconitic sandstone and gray shale, becoming mostly shaly glauconitic sandstone at the base.

Flathead formation.—The Flathead is estimated to be 150 feet thick and consists of an upper and lower sandstone member separated by a middle shale zone. The upper sandstone is fine- to coarse-grained gray sandstone; the middle shale member is dark gray to green to glauconitic. The lower sandstone member is fine- to coarse-grained, and gray to white in color. The Flathead formation overlies the pre-Cambrian.

UNCONFORMITIES

Notable unconformities occur at the base of the Fort Union, Cloverly, Sundance, Gypsum Spring, Dinwoody, Phosphoria, Tensleep, Amsden, Madison, Jefferson, Bighorn, and Flathead formations.

SURFACE STRUCTURE

The Elk Basin structure is a northwest-southeast-trending asymmetrical anticline (Figs. 2 and 5) approximately 5 miles wide by 10 miles long. The dips on the southwest flank of the structure range from 19° to 24°, and the dips on the north-

east flank of the structure range from 20° to 50°. The structure has approximately 5,000 feet of closure. The youngest beds known to be involved in the folding are Fort Union beds of Paleocene age. Since no no unconformity has been recognized within the Fort Union, it is considered that the Elk Basin field obtained its present relief largely in post-Paleocene, probably in early Eocene, time.

SUBSURFACE STRUCTURE

The subsurface structure (Fig. 6) as contoured on the Second Frontier sand by H. T. Morley, indicates a local closure centering ground the NE. ¼ of Sec. 24, T. 58 N., R. 100 W., with a number of fault blocks persent in the south end of the Elk Basin field. The Tensleep contour map does not conform entirely with the Second Frontier contour map since a local closure is shown on the Tensleep in the NE. ¼ of Sec. 31 and the SE. ¼ of Sec. 30, T. 58 N., R. 99 W., in Park County, Wyoming, which is not apparent on the Second Frontier contour map. However, there is no appreciable shift in the axis of the Elk Basin structure with depth. The lack of conformity between the contouring on the Second Frontier and on the Tensleep is ascribed to adjustments in the shale zones in the Upper Cretaceous.

FAULTING

The Elk Basin anticline is broken by four distinct groups of faults. Three of the fault groups are normal faults, and the fourth is a thrust fault. Early writers[10] described the sets of normal faults, and, more recently, C. E. Dobbin[11] mapped the thrust fault at the southeast end of the Elk Basin field. Two sets of northeast-trending normal faults approximately parallel each other. The third set of normal are strike faults which cut the other two sets of normal faults at right angles. Estabrook, on the basis of field data, determined that the northeast-trending normal faults, downthrown on the south, probably occurred first; the northeast-trending faults, downthrown on the north, occurred next; and the northwest-trending strike faults offset the two previously mentioned groups, and were last. The dips of the fault planes in the northeast-trending faults, downthrown on the north, range from 40° to 75°. The fault planes of the two strike faults mapped dip 65° east, and the throw ranges from almost nothing to 170 feet. Both longitudinal and transverse cross sections of the Elk Basin field have been studied, by use of

[10] E. L. Estabrook, "Faulting in American Oil Fields," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 2 (March-April, 1923), p. 95.
J. S. Irwin, "Faulting in the Rocky Mountain Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 2 (February, 1926), p. 105.
C. W. Washburne, "Epi-Anticlinal Faults of Elk Basin, Wyoming," *Bull. Geol. Soc. America*, Vol. 37 (1927)
John G. Bartram, "Elk Basin Oil and Gas Field, Park County, Wyoming, and Carbon County, Montana," *Structure of Typical American Oil Fields*, Vol. II, Amer. Assoc. Petrol. Geol. (1929), pp. 581–83.

[11] C. E. Dobbin *et al.*, "Geologic and Structure Map of the Elk Basin Oil and Gas Field and Vicinity, Park County, Wyoming, and Carbon County, Montana," *U. S. Geol. Survey* (1944).

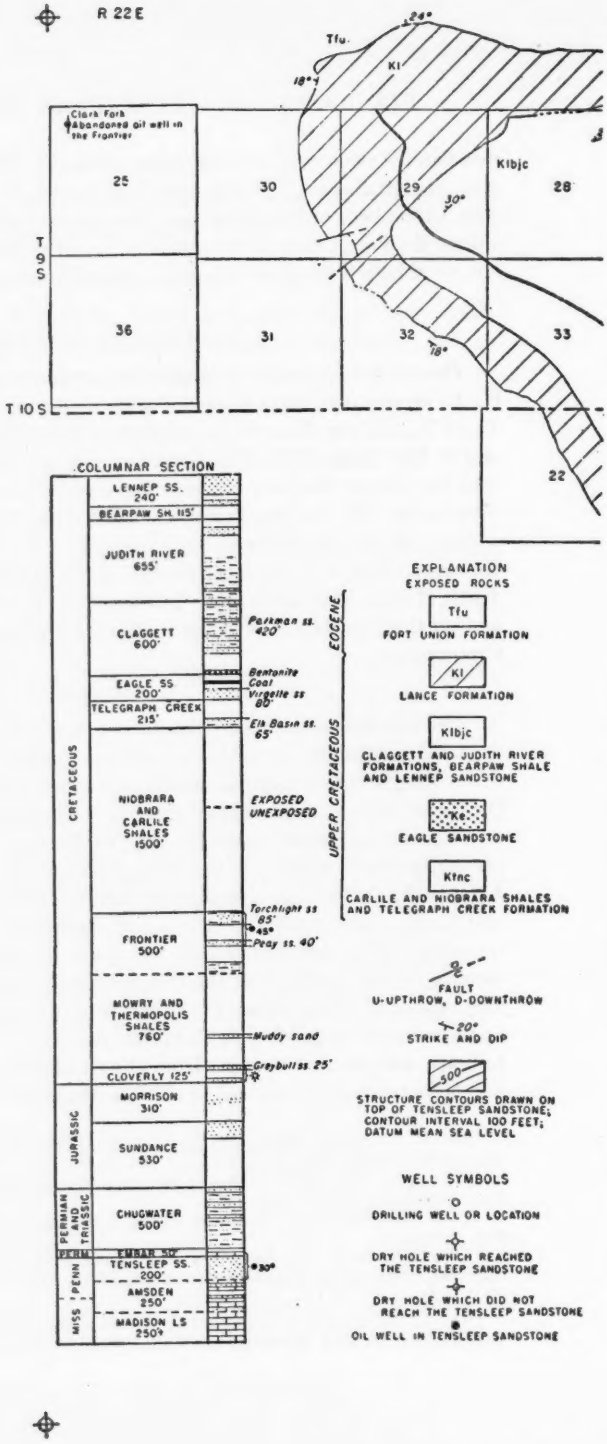
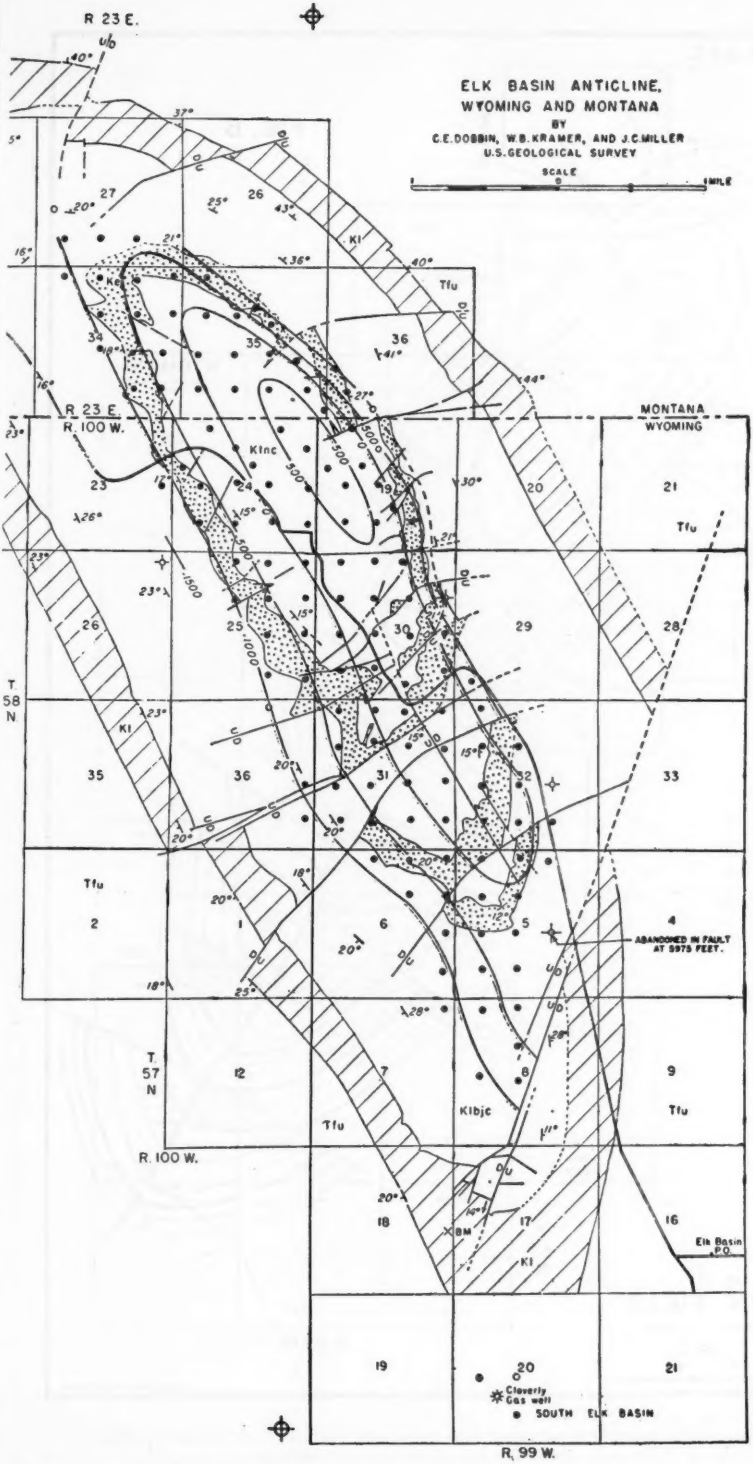


FIG. 5.—Geologic and structure map



of Elk Basin by C. E. Dobbin *et al.*

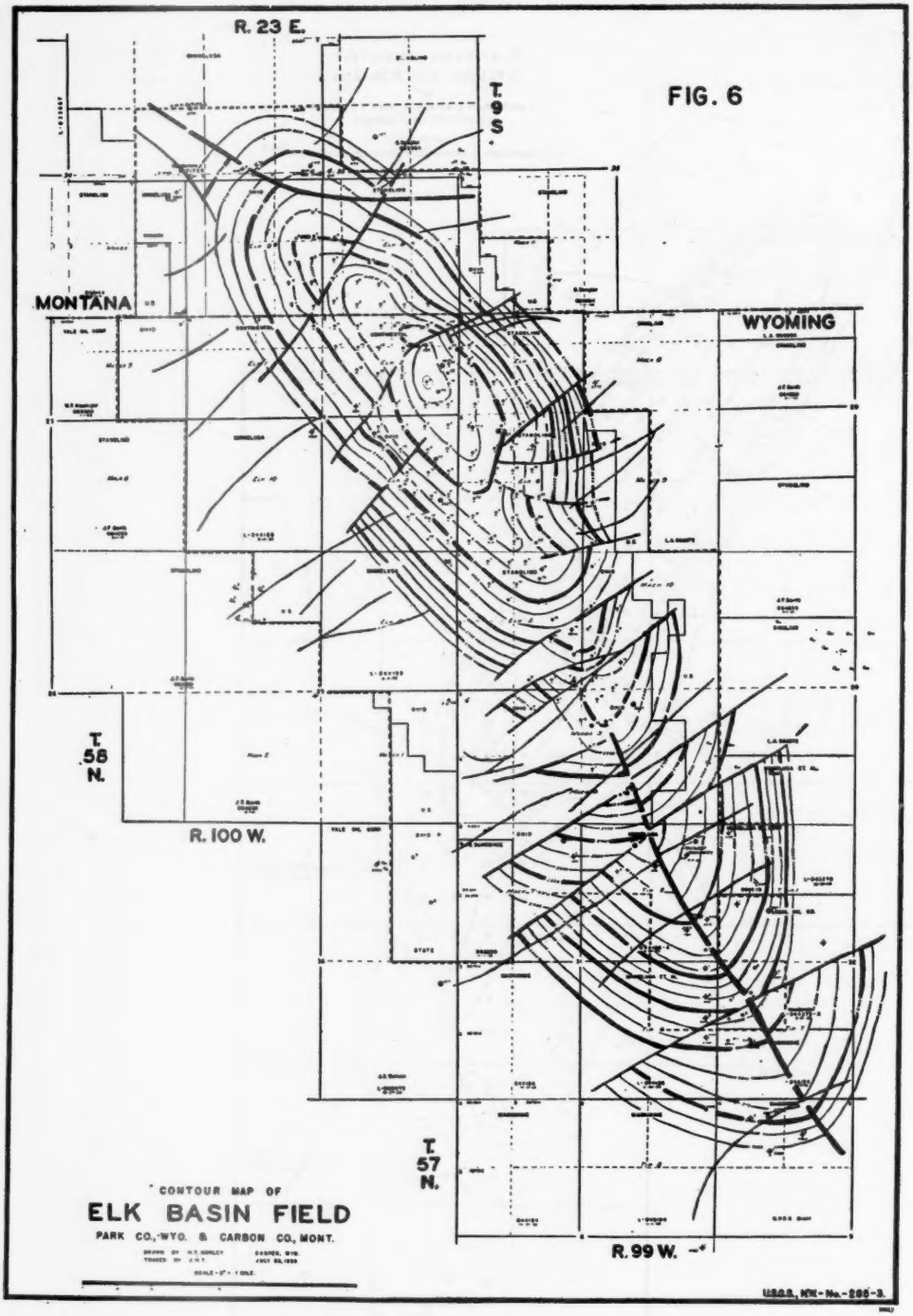
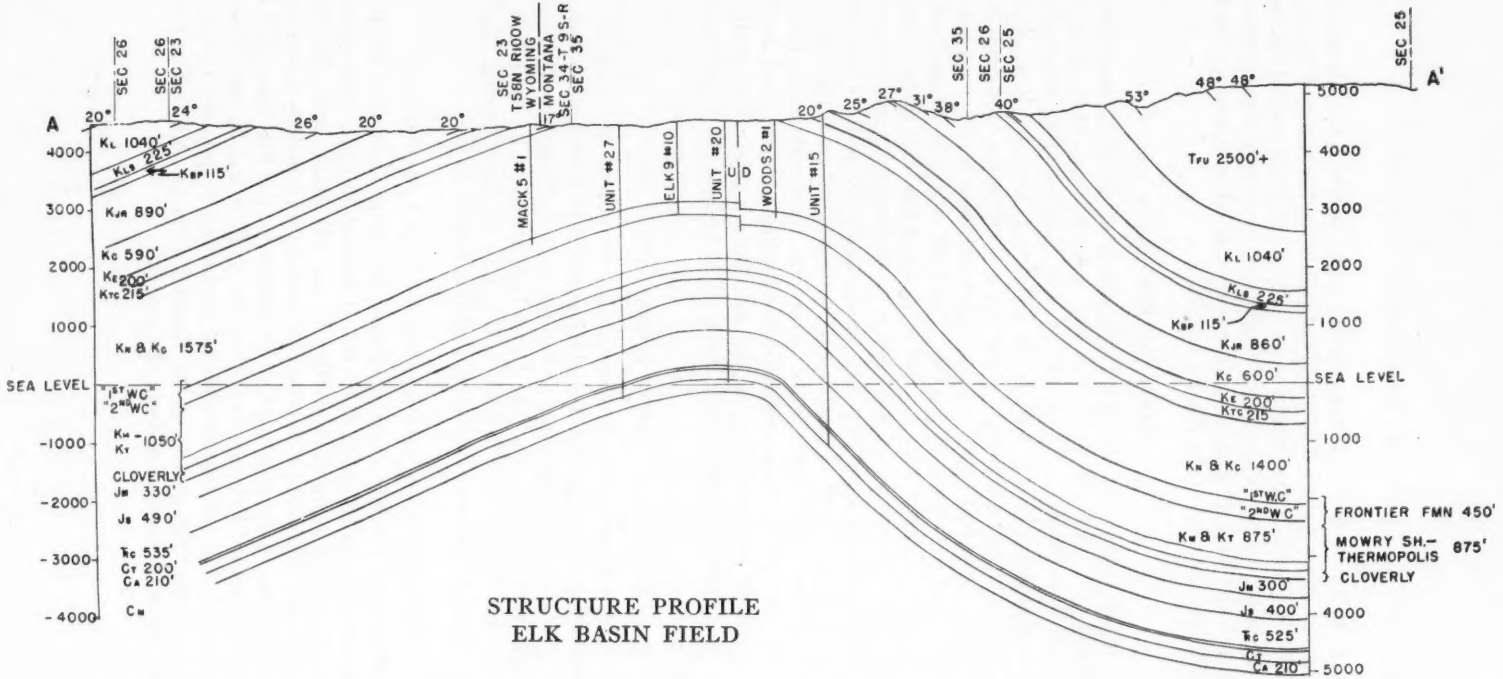


FIG. 6.—Structure map of Elk Basin field contoured with 50-foot interval on top of Second Frontier sand by H. T. Morley, 1926. This map shows intricate faulting.



STRUCTURE PROFILE
ELK BASIN FIELD

FIG. 7.—Southwest-northeast-structure profile of Elk Basin field along line *AA'* shown in Figure 2. Symbols: Tft, Fort Union; Kl, Lance; Kls, Lennep sandstone; Kbp, Bearpaw shale; Kjr, Judith River; Kc, Claggett; Ke, Eagle; Ktc, Telegraph Creek; Kn and Kc, Niobrara and Carlile shale; Kwc, Wall Creek; Km, Mowry; Kt, Thermopolis; Jm, Morrison; Js, Sundance; Trc, Triassic Chugwater; Ct, Tensleep; Ca, Amsden; Cm, Madison.

electric logs, in an attempt to determine the depth to which the normal faults persist. Present information indicates normal faulting in the Mowry-Thermopolis section, but that there is no evidence to indicate the effect of normal faulting at any horizon below the top of the Muddy sandstone member of the Thermopolis. The normal faults have affected the accumulation of oil on upthrown blocks in the Second Frontier sand in the Elk Basin field.

THRUST FAULTING

The northeast-southwest-trending fault, shown on Dobbin's map (Fig. 5) in Sec. 28 and 33, T. 58 N., R. 99 W., and Secs. 5, 8, and 17, T. 57 N., R. 99 W., is a thrust fault downthrown on the southeast. The McKinnie Oil Company's No. 12 N. P., drilled in the NE. $\frac{1}{4}$, NW. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 5, T. 57 N., R. 99 W., Park County, Wyoming, had a repetition of the top of the Frontier formation. In this well the Frontier was first encountered at 2,679 feet, datum plus 2,203 feet, and also at 5,680 feet, datum minus 980 feet. The fault zone was encountered at a depth of 4,350 feet, datum plus 550 feet. The dip of the fault plane is approximately 82° NW. The throw of the fault is approximately 3,200 feet and the horizontal displacement 7,400 feet. The movement involving the thrust fault is considered to be the result of compressive stress applied from the west. Since there is no marked displacement of the Lance Fort Union contact on the southwest flank of the structure it is considered that the displacement along the thrust fault occurred by underthrusting on the downthrown side of the fault, with accompanying squeezing and increase in dip of the beds on the downthrown side of the fault.

AGE OF FAULTING

Both systems of northeast-southwest transverse normal faults cut the Fort Union formation. Consequently, the three systems of normal faults are considered, in the absence of any noted unconformity in the Fort Union, to be post-Paleocene in age. Similarly, the Fort Union beds are offset by the thrust fault on the southeast flank of the Elk Basin field and, by similar reasoning, the thrust fault is considered to be post-Paleocene, probably Eocene, in age.

FIRST AND SECOND WALL CREEK SANDSTONE PRODUCTION

The First Wall Creek is shaly sandstone, and its production is erratic and covers an area of approximately 800 acres. It has accounted for approximately 5 per cent of the total light-oil production in the Elk Basin field. The Second Wall Creek sandstone production covers an area of approximately 500 acres, and 95 percent of the cumulative light-oil production in the Elk Basin field is attributed to this second Frontier zone. There are 99 First and Second Wall Creek sandstone wells, and their cumulative oil production to January 1, 1947, was 12,157,158 barrels. The gravity of the Frontier oil is 43° A.P.I. The Frontier wells were drilled to an average depth of 1,500 feet.

GREYBULL SANDSTONE PRODUCTION

In 1922, gas was discovered in the Greybull sandstone at an approximate depth of 2,600 feet in a well in Sec. 24, T. 58 N., R. 100 W. Four Greybull sandstone gas wells drilled in the north end of the field had a total initial daily open flow of 160 million cubic feet of gas with a shut-in casinghead pressure of 925 pounds.

PHOSPHORIA-TENSLEEP PRODUCTION

The discovery well in this zone was the Minnelusa Oil Company's No. 1 Henderson T. P. No. 2, Sec. 31, T. 58 N., R. 99 W., Park County, Wyoming, completed, January 8, 1943, with a flowing initial production of 1,200 barrels of oil in 12 hours. The Phosphoria-Tensleep production is unitized and 5,000 acres are considered proved for production in this zone. The gravity of the Phosphoria-Tensleep oil is 30° A.P.I. There are 129 wells in the zone and the depth of the producing section ranges from 3,900 to 6,000 feet, with an effective oil-producing thickness of 100 feet. Nineteen hundred feet of productive closure is indicated in the Phosphoria-Tensleep zone. The Phosphoria-Tensleep reservoir has a delayed water drive, and wells produce by pumping and flowing. The cumulative Phosphoria-Tensleep oil production to January 1, 1947, was 11,926,248 barrels.

MADISON PRODUCING ZONE

The Madison discovery well, Stanolind Unit No. 38-M, in Sec. 24, T. 58 N., R. 100 W., was completed in 1946, flowing 247 barrels of 30° gravity oil per day. The depth of the producing zone in the Madison is from 4,350 to 5,013 feet with 663 feet of penetration in the Madison. The productive limits of the Madison are undetermined.

UNTESTED POSSIBLE OIL- AND GAS-PRODUCING ZONES

Untested possible producing zones are the Jefferson dolomite the Bighorn dolomite, and the Flathead sandstone, of Middle Devonian, Upper Ordovician, and Middle Cambrian age, respectively.

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VOL. 32, NO. 1 (JANUARY, 1948) PP. 68-81, 4 FIGS.

JURASSIC OVERLAP IN WESTERN NEW MEXICO[1]

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Albuquerque, New Mexico

ABSTRACT

Southward changes in Jurassic stratigraphy along the east side of the Cebolleta Mesa give a clear picture of the nature of the southern margin of Jurassic deposition in western New Mexico. Results of the measurement of nine sections are shown graphically and discussed in terms of the structural and stratigraphic relations of the units. The Wingate sandstone is divided into three members and the Morrison formation into four. These members thin and become coarser southward and progressively overlap a positive area in that direction.

The wedge of Jurassic rocks lies between the Chinle shale (Upper Triassic) and the Dakota (?) sandstone (Upper Cretaceous). Its disappearance southward is due (1) to thinning against a positive area and (2) to truncation by the pre-Dakota erosion surface.

INTRODUCTION

During the months of February through May, 1946, a detailed study was made of the changes in Jurassic strata along the line of cliffs between Mesa Gigante and the head of Rio Colorado in Valencia County, New Mexico (Fig. 1). The data here presented are a result of this work. It is believed that they may be of general interest because of their bearing on some problems of delineation of a part of the southern margin of Jurassic deposition in the Rocky Mountain and Colorado Plateau provinces. Since the strata are very well exposed in this belt of outcrops, it has been possible to establish some lateral relationships of units more accurately than is perhaps possible along other north-south lines in New Mexico. Accordingly, the information presented may be helpful in interpreting Jurassic relationships elsewhere in the Southwest.

Scope of work.—Nine sections were measured at intervals as shown in Figure 1, in order to establish the nature of change of the exposed rocks from north to south. The mappable units shown in Figure 2 were traced wherever possible between the sections. Although much attention was given to the lithologic characteristics, more emphasis was placed the lateral changes in the units.

Previous work.—The general geologic features of the area were first mapped and described in 1885 by Dutton whose work was largely concerned with the adjoining areas north and west.[3] Darton examined the area and included a map and report in his "Red Beds" bulletin.[4] The coal-bearing Cretaceous rocks at the north

[1] Manuscript received, May 15, 1947.

[2] Geologist. Grateful acknowledgment is here made to Professors V. C. Kelley and S. A. Northrop, of the University of New Mexico, for field and office counsel while this study was in progress. C. B. Read of the United States Geological Survey has permitted review of notes on published sections.

[3] C. E. Dutton, "Mount Taylor and the Zuni Plateau," *U. S. Geol. Survey 6th Ann. Rept.* (1885), pp. 113–202.

[4] N. H. Darton, " 'Red Beds' and Associated Formations in New Mexico," *U. S. Geol. Survey Bull. 794* (1928), pp. 109–37.

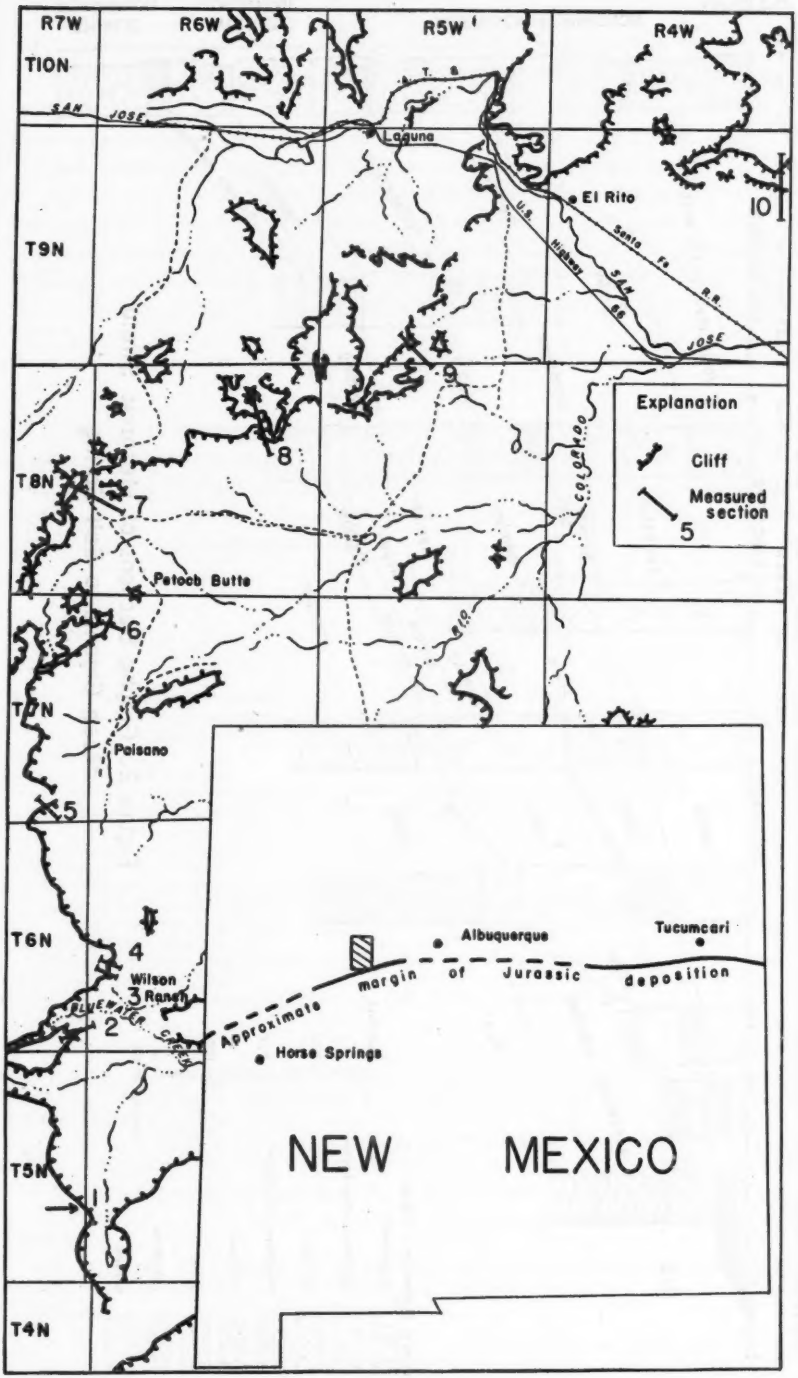

FIG. 1.—Index map.

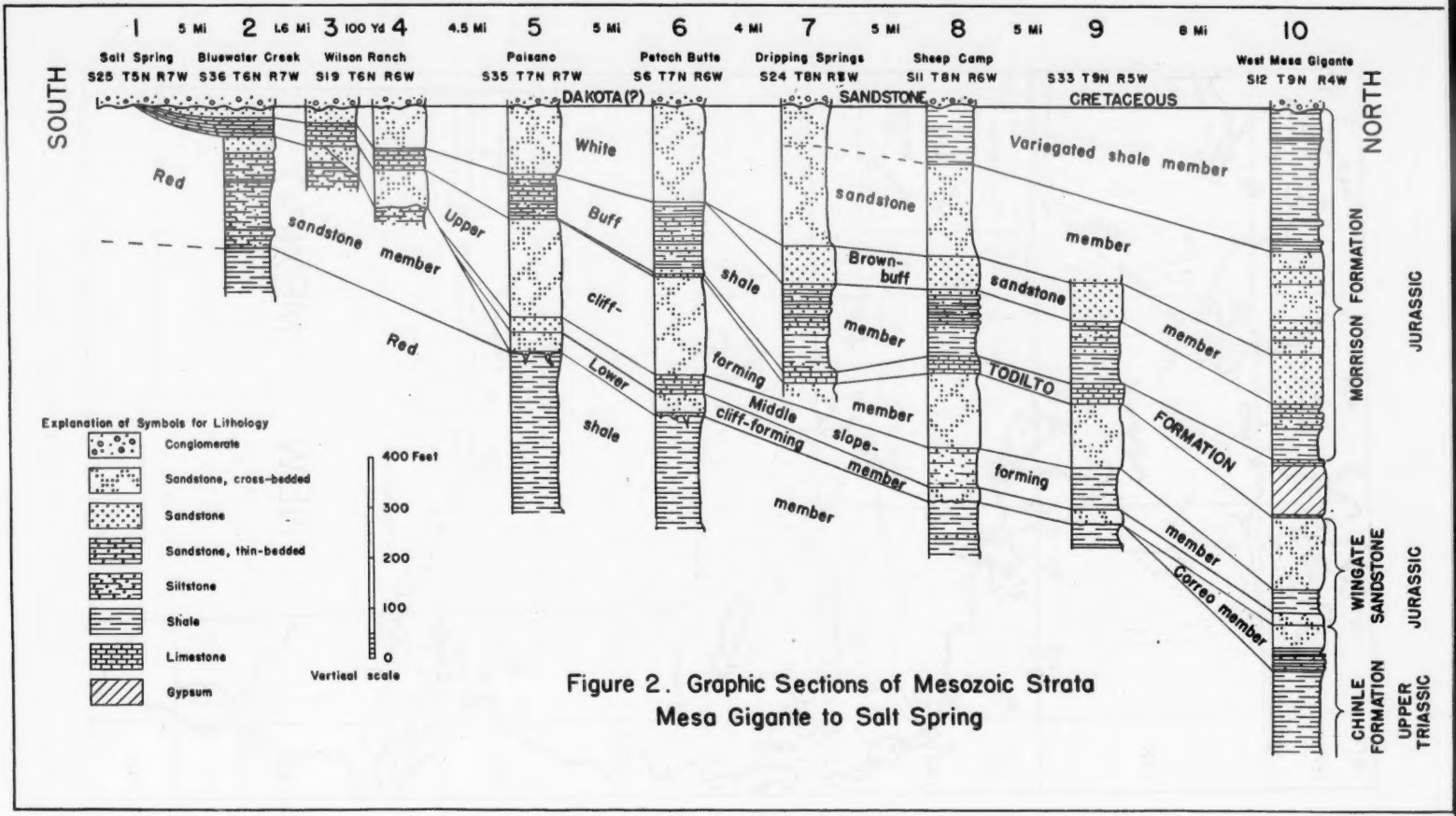

Figure 2. Graphic Sections of Mesozoic Strata
Mesa Gigante to Salt Spring

FIG. 2.—Graphic sections of Mesozoic strata (Mesa Gigante to Salt Spring).

have been described by many workers[5] who restricted their descriptions of the Jurassic rocks to the beds immediately underlying the Cretaceous.

A locality in this area was included in the correlation of the Jurassic rocks of northwestern New Mexico by Baker, Dane and Reeside[6] who used for that purpose a section measured by Darton at El Rito railroad siding.[7] Kelley and Wood published a map which included section 10 used in this report.[8] Wright[9] mapped the Tertiary and Quaternary geology of the area but was not greatly concerned with bedrock geology.

Stratigraphy

A section measured at the west end of Mesa Gigante (Fig. 2, section 10) is comparable in almost every detail with the section measured 2 miles away at El Rito railroad siding by Darton.[10] Section 10 is given here because it is the thickest section of Jurassic rocks in the area and also includes every unit under discussion. The description of the section follows.

	Thickness of Unit (Feet)	*Thickness to Top of Chinle Formation (Feet)*
Dakota (?) sandstone (top eroded)		
18. Fine- to medium-grained, white-to-buff sandstone, weathered rusty brown, jointed	30	
Morrison formation		
Variegated shale member		
17. Gray shale and white sandstone, mostly covered	51	986
16. White to light gray soft shale with nodular, greenish beds, thin, red or purple clay shale here and there	146	935
15. Mostly soft white-to-green shale, with soft sandstone here and there	40	789
White sandstone member		
14. Buff-to-white, medium-grained, cross-bedded sandstone	157	749
13. Buff, medium-grained, cross-bedded sandstone with thin, brick-brown, medium-grained sandstone	49	592
Brown-buff sandstone member		
12. Hard, massive, banded buff to red-brown, fine- to medium-grained sandstone cliff-maker	90	543
11. Red-brown, tan, buff and light gray, soft, friable, cross-bedded sandstone	9	453

[5] For a detailed bibliography, see C. B. Hunt, "Geology and Fuel Resources of the Southern Part of the San Juan Basin, New Mexico," *U. S. Geol. Survey Bull. 860B*, Pt. 2 (1936), The Mount Taylor coal field, pp. 33, 34.

[6] A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., "Correlation of the Jurassic Formations of Parts of Utah, Arizona, New Mexico and Colorado," *U. S. Geol. Survey Prof. Paper 183* (1936), p. 17.

[7] *Ibid.*, p. 43. Complete bibliography of the Jurassic literature of northwestern New Mexico.

[8] V. C. Kelley and G. H. Wood, "Oil and Gas Investigations Preliminary Map 47," *U. S. Geol. Survey* (1946).

[9] H. E. Wright, Jr., "Tertiary and Quaternary Geology of the Lower Rio Puerco Area, New Mexico," *Bull. Geol. Soc. America*, Vol. 57 (1946), pp. 383–456.

[10] Darton, *op. cit.*, p. 120.

	Thickness of Unit (Feet)	Thickness to Top of Chinle Formation (Feet)
Buff shale member		
10. Buff, tan, brown clay shale and sandstone. Lower part dominantly shale	124	444
Todilto formation		
9. White gypsum, mottled gray, with clay laminations. 3- to 6-inch limestone beds in top 15 feet	95	320
8. Laminated gray limestone with white clay intercalated	6	225
7. Laminated, light gray limestone with thin calcareous clay and sandstone	6	219
Wingate sandstone		
Upper cliff-forming member		
6. Pink- to red-brown, massive fine-grained, cross-bedded sandstone, upper 26 feet white	146	213
Middle slope-forming member		
5. Red-brown, silty clay-shale, with thin, fine-grained buff-to-green soft sandstone here and there	40	67
Lower cliff-forming member		
4. Buff-to-pink, medium-grained sandstone, massively cross-bedded, clean quartz and chalcedony	27	27
Chinle formation		
Correo sandstone member		
3. Light brown to brownish white, medium-grained, irregularly bedded, cross-laminated sandstone, some hematite grains	45	
2. Red-brown, fine-grained, clayey sandstone containing lenses and beds of limestone- and jasper-pebble conglomerate	53	
Shale member		
1. Red-brown to purple clay-shale, irregularly streaked gray-white	155	
Base not exposed		

TRIASSIC

CHINLE FORMATION

The Chinle formation is the lowest stratigraphic unit exposed in the area.

Shale member of Chinle formation.—The shale member consists of about 1,000 feet of clay shale and siltstone. The color is typically red- to purple-brown, due to the presence of hematite, with spots and thin bands of greenish white. Erosion has generally exposed the member in flat valleys or slopes beneath cliff-formers. Where well exposed the shale weathers into badland topography. Soft silty clay or siltstone is predominant, but thin-bedded, fine-grained sandstone, limestone, calcareous pebble conglomerate, and lenses of selenite are interbedded here and there. The upper contact shows an uneven surface with some sharp irregularities that are interpreted as gullies formed prior to deposition of the overlying beds.

Yellow limonite concretions are rare. A limestone bed 2 feet thick contains a number of fresh-water gastropods. This is the second record of non-marine gastropods in the Triassic of North America.[11]

[11] According to Stuart A. Northrop (personal communication of March 30, 1947):
"Undescribed species of several genera, such as *Scalez* or *Viviparus*, *Lioplacodes*, and possibly *Amnicola* or *Valvata*, appear to be represented. Junius Henderson ("Fossil Non-Marine Mollusca of North America," *Geol. Soc. America Spec. Paper 3* (1935), pp. 23–24) cited only pelecypods, though

Red sandstone member of Chinle formation.—A fine-grained sandstone member with a measured thickness of 164 feet occupies the top of the Chinle formation at the south end of the area. It is a lighter red than the shale below it and contains greenish white spots and bands. The sandstone beds range from 2 to 131 feet in thickness and stand out in ledges from a weathered shale slope. They are even-bedded. A shaly structure is apparent in weathered blocks. The fragments are very fine-grained, subangular, poorly sorted quartz with some chalcedony. The rock is soft and friable and cemented by hematite. No fossils or concretions were noted. The beds appear to have low porosity.

Correo sandstone member.—This member was designated by Kelley and Wood in 1946 from exposures one mile north of the settlement of Correo.[12] It consists of about 90–120 feet of interbedded sandstone and conglomerate. The beds are dominantly dark red-brown, but some sandstone beds are buff to pale brown. The sandstone and conglomerate are unevenly and irregularly cross-bedded and form a low cliff with receding ledges above the Chinle shale member. Most of the beds are clayey and a few thin intercalated clay beds contain breccias. Quartz and chalcedony predominate, but about 3 per cent of other minerals are present. Hematite appears both as a cement and as included grains. The included hematite grains appear to be altered magnetite. The grains are subangular to subrounded. The beds contain petrified logs, algal-like limestone pellets, clay lentils, breccias, bone fragments, phytosaur teeth, coprolites, and, rarely, barite as nodules and druses on bedding planes. The fresh-water clam, *Unio*, is also found. The beds range from moderately to extremely porous and are permeable.

JURASSIC

WINGATE SANDSTONE

The term was originally applied by Dutton to exposures a few miles north of Fort Wingate in northwestern New Mexico.[13] Wingate was applied to all the beds between the Chinle shale and the Todilto limestone. Dutton apparently recognized the fact that the massive pink sandstone cliff was composed of several beds when he said,

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Yen and Reeside ("Triassic Fresh-Water Gastropods from Southern Utah," *Amer. Jour. Sci.*, Vol. 244 (1946), pp. 49–51) later described two species of gastropods.

"It may be noted further that only two species of pre-Jurassic non-marine gastropods are known from the West, although several species have been described from Pennsylvanian strata of Illinois, Ohio, and especially Nova Scotia. Walcott's supposed Mississippian gastropods from Nevada have been shown by F. Stearns MacNeil "Fresh-water Invertebrates and Land Plants of Cretaceous Age from Eureka, Nevada," *Jour. Paleon.*, Vol. 13, No. 3 (May, 1939), pp. 355-60, to be of Lower Cretaceous age.

"On the other hand, fresh-water and air-breathing gastropods are not uncommon in the Jurassic of the Rocky Mountain region; see Henderson (*op. cit.*, pp. 24–25) and a recent paper by Teng-Chien Yen and John B. Reeside, Jr. ("Fresh-Water Mollusks from the Morrison Formation (Jurassic) of Sublette County, Wyoming," *Jour. Paleon.*, Vol. 20, No. 1 (January, 1946), pp. 52–58."

[12] V. C. Kelley and G. H. Wood, *op. cit.*

[13] Dutton, *op. cit.*, pp. 136–37.

It is in reality a group or sub-group of sandstones in which the lines of bedding are generally but not always effaced.[14]

Darton recognized two members in the Wingate:

> . . . an upper one of gray cross-bedded sandstone weathering in rounded forms and a lower one of red massive sandstone weathering in vertical cliffs with columnar structure.[15]

A section[16] which Darton measured at a locality near that of section 8 (Fig. 2) of this report showed a three-fold division of the Wingate.

In the present paper the rocks which have been termed Wingate are subdivided into three members designated as the lower cliff-forming member, the middle slope-forming member, and the upper cliff-forming member.[17]

Lower cliff-forming member.—This sandstone member is 30–40 feet thick. Its color on weathered surfaces is pink- to red-brown but on fresh surfaces it is pink to pale buff. The general appearance is that of one thick bed forming a massive cliff, which weathers into columnar structure (Fig. 3A, lower part of cliff labelled Jw.) A few beds, each less than 2 feet thick, occur at the base. The thick cliff-former is even bedded and tangentially cross-laminated. The thin beds are irregular conglomeratic sandstone and shale. The sandstone is composed of subrounded, fine- to medium-grained quartz and chalcedony. The shale is dark red and silty. Hematite is the principal cementing material, forming a film around many of the grains. In the south the basal sandstone is conglomeratic, containing fragments up to 2 inches in diameter in some localities. The sandstone beds appear to be very porous.

This member maintains a relatively uniform thickness along the line of sections. It rests directly on the Chinle shale or Correo member without thin basal beds in the northern part of the area and at the south end of the area the basal sandstone or conglomerate fills small gullies in the underlying shales. The top is drawn at the first shale break above the massive sandstone.

Middle slope-forming member.—This member consists of shale with some interbedded siltstone, and ranges from 30 to 83 feet in thickness. It has a dark red color in contrast to the purplish aspect of the Chinle shale. Its outcrop is either a bench or slope between the Wingate cliffs. Bedding within this member is difficult to determine, excepting where a thin siltstone bed has been leached to a pale green or white. The shale beds are silty and show little cleavage. Clay galls and ripple

[14] *Ibid.*, p. 137.

[15] *Ibid.*, p. 116.

[16] *Ibid.*, p. 117.

[17] Since submission of this paper for publication, A. A. Baker, C. H. Dane, and J. B. Reeside, Jr. ("Revised Correlation of Jurassic Formations of Parts of Utah, Arizona, New Mexico, and Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 9 (September, 1947)) have extended the name Entrada sandstone "to include the sandstone at the type locality of the Wingate sandstone, and the name Wingate is retained for the sandstone forming the lower part of the Glen Canyon group, with the understanding that the original type locality of the Wingate has been abandoned." The upper cliff-forming member of this paper is therefore the equivalent of the Entrada sandstone, the middle slope-forming member, and the lower cliff-forming member are referred to the Glen Canyon group.

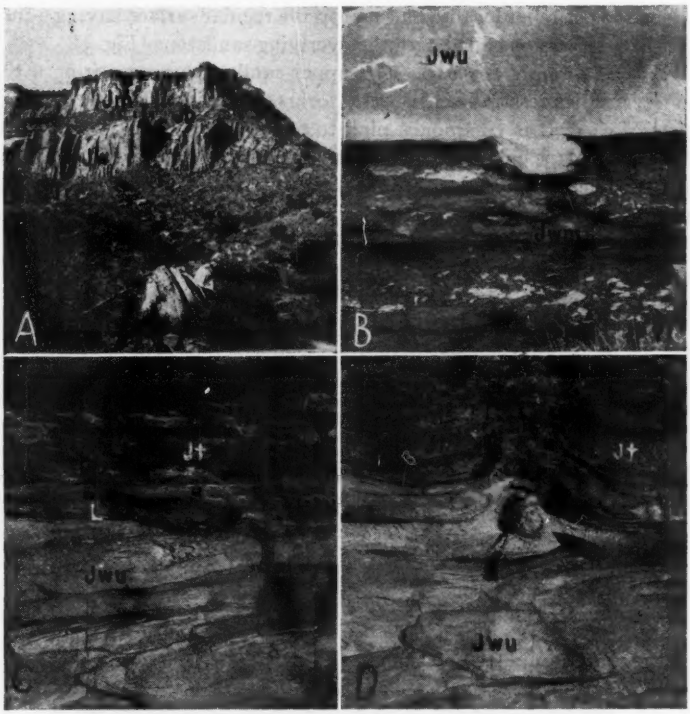

FIG. 3

A. Section 5 at Paisano, showing typical rounded outcrop of Wingate in lower cliff (Jw), receding slope of Buff shale member (Jb), and straight massive white cliff of Morrison sandstone (Jm), capped by dark Dakota (?) sandstone. The lowest talus slopes cover the Chinle formation (Trc).
B. Base of upper cliff-forming member of Wingate sandstone (Jwu) showing one-foot-wide channel of sandstone in underlying middle slope-forming member (Jwm).
C. Base of thin-bedded Todilto limestone (Jt), showing wedge-shaped lens (S) of upper cliff-forming member of Wingate sandstone (Jwu) in back of hammerhead tonguing above limestone lens L.
D. Mudball at contact between upper cliff-forming member of Wingate sandstone (Jwu) and Todilto formation (Jt).

marks, which are interpreted as of aqueous origin, are present. These beds appear to have low porosity.

The beds of this member are coarser at the south where siltstone and fine-grained sandstone become more prominent. In many places, it is included in a single cliff with the upper and lower members and is difficult to recognize except by bedding planes (Fig. 3A). Slight recessions in the cliff and a muddy zone between bedding planes are evidences of its presence at the south. Where the clay-shale sequence is prominent, its base is marked by an undulating surface having

about one foot of relief locally, and its top is a regular surface having 6-inch-deep channel-like depressions filled with the overlying sandstone (Fig. 3B).

Upper cliff-forming member.—The upper sandstone ranges from a thin film to 196 feet in thickness and consistently forms a prominent cliff or bluff in northern New Mexico. It is commonly pink to red in color and has a distinct white zone at the top. It is even-bedded and massively cross-laminated. The grains are subangular, fine, well sorted, frosted quartz with about 10 per cent of red, black, and yellow chalcedony. It appears highly porous and permeable.

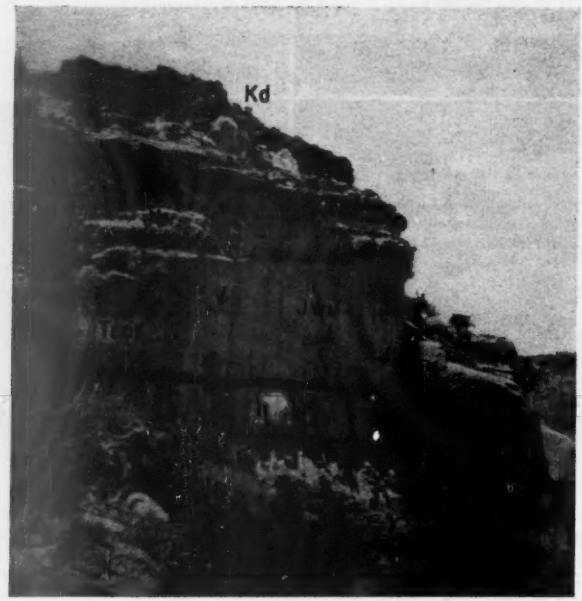

FIG. 4.—Overlap of Wingate sandstone by Morrison formation. Conglomeratic white upper cliff-forming member of Wingate sandstone (Jwu) thinning to an edge and truncating fine-grained red sandstone member of Chinle formation (Trcr). Arrows point to contact. Bed labelled Trcr is 31 feet thick. Wingate thickens to 80 feet at extreme right. Cliff faces east. Buff shale member (Jb) overlaps Wingate southward.

This sandstone coarsens appreciably southward as streaks of granules and pebbles appear. The base is regular where it is in contact with the middle Wingate soft member, but where it rests on the red sandstone member of the Chinle formation it is irregular (Fig. 4). Clay balls occur at the top locally (Fig. 3D). The color changes considerably southward. The white zone at the top thickens downward toward the south, the entire unit becoming completely pale buff-to-white sandstone.

TODILTO FORMATION[18]

The Todilto limestone and gypsum unit has a maximum thickness of 110 feet. In many places its outcrop is a dark gray limestone ledge, overlain by a massive dirty white bed of gypsum. The limestone member is light gray, laminated, and thinly bedded. The gypsum is white with gray mottling and laminations of clay that are locally contorted. The limestone is commonly fetid. It contains sandstone beds in the bottom part. Lenses of gypsum occur in the limestone. Thin 3 to 6-inch limestone beds occur in the upper 15 feet of gypsum.

The limestone is thinner and more argillaceous where it is overlain by gypsum in the northern part of the area. It thickens to 40 feet southward where there is no overlying gypsum and then thins to a 40-inch calcareous sandstone containing lenses where it tapers to a thin edge. The base of the limestone intertongues with the upper-forming member of the Wingate sandstone (Fig. 3C); the top is irregular as though it were a solution surface.

The gypsum is only present as a massive bed above the limestone in the northern part of the area. North of U.S. Highway 66 at Mesita the gypsum is 80 feet thick. Within a distance of $\frac{1}{2}$ mile south of the highway it has thinned to one foot. Since the intervening outcrop is covered by alluvium, the precise manner of its thinning can not be ascertained.

MORRISON FORMATION

The term "Morrison formation" in northern New Mexico has been used for the strata between the Todilto formation and the Dakota (?) sandstone. In this paper, following Kelley and Wood, the "Morrison" is separated into mappable field units.

Buff shale member.[19]—A conspicuous interval of interbedded, thin sandstone, siltstone, and shale up to 130 feet in thickness lies above the Todilto. The beds are banded white, buff, red, red-brown, and pale green. They commonly form a slope back of a bench eroded on Todilto. Shale predominates in the lower half of this interval, which is everywhere covered by talus. The upper half appears as thin ledges beneath a nearly vertical cliff. Green or red clay partings separate some of the beds. The sandstone is thin-bedded, silty, and friable. The sandstone is made up of very fine-grained, poorly sorted, subangular quartz and chalcedony. The shale beds are silty and clayey. The grains are cemented by calcite with minor quantities of hematite and gypsum.

The buff shale member becomes coarser toward the south although it consistently maintains thin bedding, green and red clay partings, and some shale. The gradation from shale through siltstone to sandstone from north to south is accompanied by a marked reduction in the number of beds and the thickness of the

[18] Baker, Dane, Reeside, *op. cit.*, now make use of the term Wanakah formation to include the Todilto limestone and gypsum.

[19] Baker, Dane, and Reeside, *op. cit.*, possibly would refer this unit to the San Rafael group and group it with the Todilto limestone and gypsum under the term Wanakah formation.

unit. It thins from 130 feet to 5 feet and maintains that reduced thickness for 4 miles before being cut out by the Dakota (?) sandstone at location 1 (Fig. 1).

Generally speaking, it grades from a shale-siltstone sequence in the north to a sandstone-siltstone sequence in the south. Where the Todilto limestone is present, the basal siltstone member locally contains reworked angular fragments of limestone. The basal bed is a pebble conglomerate on the south at Bluewater Creek. The upper limit is ordinarily marked by a thin, irregular bed of red or green clay shale, which in places contains angular sandstone cobbles and boulders.

Brown-buff sandstone member.—A sandstone 65–90 feet thick forms a prominent cliff along U.S. Highway 66 a few miles east of Laguna Pueblo. It is a buff-to-brown or dark brown, banded sandstone whose color on fresh fractures is pale buff. It appears to be one massive, even-bedded sandstone. Cross bedding is present but is not conspicuous. The grains are subrounded, fine- to medium-grained quartz with about 3 per cent red and black chalcedony. This sandstone is fairly porous and permeable and is the best aquifer in the area. It is the water-bearing stratum at Dripping Springs.

The brown-buff sandstone thins from 90 feet at Correo to 65 feet at Dripping Springs, a distance of 16 miles from north to south, beyond which point it becomes indistinguishable from the overlying sandstone. The base is a slightly undulating surface; the top is regular. It appears to thin and grade into the overlying sandstone beds toward the south.

White sandstone member.—The white sandstone member is a buff-to-white series of prominently cross-bedded sandstones. Some beds weather brick-brown, banded orange, yellow-ocher, and greenish gray. Its topographic expression is commonly a bluff or cliff but in many places it is eroded to a bench or gentle slope above the brown-banded sandstone (Fig. 3A). It consists of medium- to fine-grained quartz with a few chalcedony grains. All beds are slightly gypsiferous. As the overlying shale changes to sandstone toward the south, the top of the white sandstone is difficult to distinguish although it is commonly marked by a bedding plane. The white sandstone member maintains its near uniformity of grain size throughout the area. It increases in thickness southward before it is gradually truncated by the Dakota (?) sandstone, and in such localities the upper few feet may contain some interstitial white kaolin.

Variegated shale member.—This the uppermost member of the Morrison is a sequence of clay-shale and siltstone with interbedded, medium-grained, cross-bedded buff sandstone. The member is multicolored in light shades of white, gray, green, and purple. The beds are slightly gypsiferous. The base is chosen as the first persistent shale bed above the white sandstone and the top is marked by an erosional unconformity below the Dakota (?) sandstone. This series of beds perceptibly coarsens toward the south, although maintaining its variegated color until it grades into a white sandstone which is not distinguishable from the member below excepting for the presence of a few red-brown bands. It also is progressively truncated toward the south by the Dakota(?) sandstone.

Leopold noted a "kaolinized white horizon"[20] at the top of the Morrison formation in a thin irregular zone immediately below the Dakota (?) sandstone in some localities in New Mexico. In Cebolleta and Gigante Mesas the kaolinized zone has been seen in a few places and attains a thickness of as much as 5 feet.

CRETACEOUS

Dakota (?) *sandstone.*—The basal beds of the Dakota (?) range from fine-grained sandstone to pebble conglomerate, and they commonly lie above a very marked unconformity which shows as much as 30 feet of relief locally. It is a much-jointed cliff-former which weathers rusty brown. It contains wood and bone fragments.

SEDIMENTARY AND STRUCTURAL RELATIONS

The regional dip is 1°–3° N.-NW. The southward convergence is so gradual that the bedding appears parallel over most of the area.

The red sandstone member at the top of the Chinle formation is not present north of T. 6 N. and was apparently removed by erosion prior to the deposition of the lower Wingate cliff-forming sandstone.

The Correo member is essentially a floodplain deposit and has its main outcrop in the northern part of the area excepting for pre-Jurassic outliers in Secs. 7 and 8, T. 8 N., R. 5. W.

The Triassic rocks and the overlying Jurassic rocks appear conformable in the northern part of the area. However, filled channels and desiccation cracks are more numerous on this contact southward and marked truncation is present in the southern part of the area.

The Wingate sandstone members all exhibit gradual thinning and coarsening toward the south with superjacent members extending progressively farther southward. The base of the lower cliff-forming member has a conglomeratic sandstone bed which fills small gullies in the underlying shale in the southern part of the area. The middle slope-forming member is a shale containing clay galls and ripple marks on the north and a silty sandstone on the south. The upper cliff-forming member thins from 81 feet to a thin edge in the 100 yards of distance between sections 2 and 3 of Figure 2 as it truncates the red sandstone member of the Chinle formation. The upper cliff-forming member of the Wingate interfingers with the lower limestone beds of the Todilto formation. The Todilto limestone and gypsum grade into calcareous sandstone which thins to an edge southward.

The members of the Morrison formation thin and coarsen and contain fewer beds toward the south. Most of these units become finer-grained toward their

[20] Leopold inferred the kaolin to indicate that a moist climate prevailed during a part, at least, of the time between Jurassic and Cretaceous in this area. (Luna B. Leopold, "Climatic Character of the Interval between the Jurassic and Cretaceous in New Mexico and Arizona," *Jour. Geol.*, Vol. 51 (1943), pp. 56–62.)

tops but the buff shale member increases in grain size upward as well as southward. Possibly the buff shale member should be included in the Todilto formation, instead of in the Morrison formation.

The increasing coarseness of particles for a distance of 30 miles south in the Jurassic rocks suggests a source in that direction. The extension of finer clastic sediments southward above coarser sediments further suggests a recession of that source. The progressive overlap of sediments indicates the presence of a positive area which was being contemporaneously lowered by erosion.

The transgressive overlap relations of these Jurassic continental sediments are not in keeping with the concept of terrestrial transgressive overlap of deltaic or alluvial fan deposits upon a plain, valley flat, or basin floor. Such overlap produces coarser-grained younger beds extending progressively basinward. Instead, the relations that exist in these Jurassic sediments indicate progressive overlap similar to that of marine transgressive overlap in which finer-grained younger beds overlap the lower beds toward the margin of the basin. The transgressive Jurassic overlap indicates either a low area of erosion or its gradual lowering during Jurassic time with, possibly, considerable material being brought to the area from the north.

The very small discordance in dip between the Jurassic rocks and underlying Triassic rocks, the fineness of sediments, and the small amount of relief on the pre-Jurassic erosion surface indicate very moderate uplift of the flank of the positive area prior to the Jurassic deposition. The positive area during Jurassic time was a low tilted or arched continental area.

Geologic History

The Chinle formation was subjected to erosion, that removed the red sandstone member in the northern part of the area and formed an extensive floodplain prior to the deposition of the Correo sandstone member. This member, a detrital product of the Chinle formation and possibly older rocks, accumulated as a floodplain deposit during the erosion interval. After an unknown interval of time, during which the Correo sandstone was subjected to erosion and partly removed, a low geanticline developed on the south, which contributed sediments to a continental basin in the northern part of the area. These early sediments form the present lower cliff-forming member of the Wingate sandstone.

Following the deposition of the lower cliff-forming member, a body of water formed in the basin, into which fine-grained sediments from the arch on the south were contributed. These sediments now form part of the middle slope-forming member of the Wingate sandstone. This member in the central area of its deposition is water-laid, but in the marginal facies is a commingling of water-worked and wind-worked material. A slight interval of time may have elapsed prior to the deposition of the overlying upper cliff-forming member, during which time the water in the basin receded. This was followed by the deposition of the upper Wingate member which is a thick deposit of wind-laid material. It overlapped upon the flanks of the low positive area at the south.

Before the sand was consolidated, part of the basin was again covered by a body of water in which calcium sulphate and calcium carbonate were concentrated in solution. Wave and current action along the south shore of this body of water beveled the upper part of the sand and reworked it so that it interfingered with limestone which was being deposited. Subsequent evaporation resulted in the deposition of the Todilto formation. In the final stages of evaporation, the once widespread water body may have been reduced to disconnected lakes in which the final gypsum and limestone were deposited in greater thickness.

Again an unknown interval of time occurred during which some of the limestone and gypsum were indurated and the upper surface slightly dissolved and reworked by water action. A large water body again formed which subsequently received sediments that now form the buff shale member of the Morrison formation. During the time of deposition of the buff shale member, the positive area on the south may have been rising since it contributed sediments at a rate which exceeded the settling of the basin on the north, and coarser clastic materials of the upper beds extended basinward above the finer materials of the lower beds.

There followed a period of active denudation of the geanticline, during which time the basin on the north contained a water body of variable extent so that some of the sandstone beds of the brown-buff sandstone and white sandstone members are water-laid and others are eolian. The final stages of erosion of the Jurassic positive area contributed sediments to the basin which reflect by their fineness the distance of the source. These fine materials formed the variegated shale member of the Morrison formation.

Following the deposition of the variegated shale member, a long interval ensued from some time in Upper Jurassic to Upper Cretaceous time, the latter of which is represented by the Dakota (?) sandstone. During this interval the Jurassic rocks were gently tilted northward along their southern limits and truncated prior to the spreading of the Upper Cretaceous seas over the entire area.

Summary

The Wingate sandstone and Morrison formation of northwestern New Mexico show distinct lithologic changes which indicate the presence of a positive area in central and southern New Mexico in Jurassic time. Similar conditions are indicated in eastern New Mexico by the work of Dobrovolny and Summerson.[21]

The Jurassic sediments wedge to a thin edge southward as the Triassic and Cretaceous rocks converge. While this convergence is in part due to erosional removal of Jurassic rocks on the south, it is also a reflection of the thinning of the Jurassic rocks in that direction as they progressively overlap upon a Jurassic positive area. The approximate margin of sedimentary deposition in Jurassic time, as it is here inferred, is shown in Figure 1.

[21] Ernest Dobrovolny and C. H. Summerson, "Geology of Northwestern Quay County, New Mexico," *U. S. Geol. Survey Prelim. Map 62*, Oil and Gas Inves. Ser. (1946).

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PERMIAN STRATIGRAPHY AND STRUCTURE, NORTHERN CANELO HILLS, ARIZONA[1]

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ABSTRACT

Measured sections in the northern Canelo Hills show 2,223 feet of Middle Permian (Snyder Hill) limestones, dolomites, and clastics overthrust upon two distinct series of younger rocks: (1) redbeds and brown conglomerates and sandstones, probably Cretaceous in age; and (2) lava flows and interbedded tuffs and sandstones interpreted as Tertiary. Major structural events discovered are: (1) the overthrusting which started in late Cretaceous or early Tertiary time; (2) high-angle faulting trending north-south and east-west; (3) formation of an anticline whose axis trends northwest-southeast. These movements affect all rocks within the area older than a late Tertiary fanglomerate. This fanglomerate and extensive terraced gravels are the youngest rocks in the area. Some of the gravels contain interbedded, spring-deposited travertines bearing a gastropod faunule identified as late Pleistocene.

INTRODUCTION

The Canelo Hills are approximately 25 miles northeast of Nogales, Arizona, and 60 miles by road southeast of Tucson. They form a connecting link of highland between the Patagonia Mountains and the Santa Rita Mountains. The area described in this paper includes 20 square miles at the northern tip of the Canelo Hills, including Mount Hughes, high point of the range. The hills are separated from the Santa Rita Mountains by the valley of Sonoita Creek.

Most of the field work was done during the summers of 1945 and 1946. The writer is indebted to B. S. Butler, director of the thesis, for at least 10 days spent in his company in the field and to E. D. McKee who reviewed the Permian section in the northern Canelo Hills in the field, and also measured the Snyder Hill type section[2a] and made a reconnaissance study of the Permian section in the Empire Mountains with the writer. J. I. Snow made specific identification of Permian fossils from the northern Canelo Hills, and Horace G. Richards identified the faunule of gastropods from late Pleistocene travertine found in the area. F. W. Galbraith made available unpublished material on stratigraphy and structure of the Empire Mountanis, and A. A. Stoyanow and M. N. Short contributed freely of their knowledge, respectively, of the paleontology and the petrology of southeastern Arizona. The writer was the guest of R. C. Jeffcott, then owner of Rail-X Ranch, during his entire time in the field. S. F. Turner and E. D. Wilson have read the present manuscript, contributing helpful suggestions. To these and to others who assisted in various capacities, the writer is deeply indebted.

The only published work mentioning the geology of the Canelo Hills of which

[1] Condensed from a thesis entitled "The Geology of Northern Canelo Hills, Santa Cruz County, Arizona," accepted, May, 1947, by the Graduate College of the University of Arizona for the Ph. D. in geology. Manuscript received, August 23, 1947.

[2] Instructor of geology, University of Arizona.

[2a] The type section is at Snyder's Hill on the Tucson-Ajo road about 10 miles southwest of Tucson. It was described by Stoyanow.

the writer is aware, is Schrader's reconnaissance[3] of 1909. At that time, in less than 4 months, Schrader and J. M. Hill completed reconnaissance mapping of the geology of the Nogales and Patagonia quadrangles. Obviously only major features of the geology could be noted. Some of these, as age and relationship of what is now known to be Permian (Snyder Hill) limestone on the northeastern slopes of northern Canelo Hills, were incorrectly classified. The paper has been useful, however, as a starting point.

General relationships within the area of this report are shown in the map of areal geology (Fig. 1). The stratigraphy is outlined in Figure 2. It is unfortunate that no fossils have been found in beds tentatively assigned to the Cretaceous. The dating of these strata is made by comparison with sections in the Empire Mountains[4] and the Patagonia Mountains,[5] and by their relation to the overlying lavas assigned by Schrader[6] to the Miocene(?). The tentative nature of their dating is emphasized.

PERMIAN STRATIGRAPHY

All Permian strata exposed in the northern Canelo Hills are interpreted as being part of a block thrust over younger strata. The movement probably began in late Cretaceous or in Tertiary time. The Permian overrides a surface carved by erosion of Tertiary(?) volcanic rocks and Cretaceous(?) sediments termed in this paper, "Canelo redbeds," for their characteristic occurrence in the canyons of the northern Canelo Hills.

The lowest 500 feet of the Permian section are composed of interbedded sandstones, limestones, and dolomites. The sandstones are red, the limestones and dolomites mostly gray. No fossils have been found in this part of the sequence (Fig. 3 and descriptions of measured sections).

The lowest fossiliferous limestone contains numerous spines of *Archaeocidaris*, bellerophontids, *Composita* sp., *Nucula* sp., turritellids, a bryozoan reef, and *Camerophoria deloi*. In short, an assemblage with strong Snyder Hill affinities is represented. Stoyanow[7] considers the presence of *Camerophoria deloi* especially diagnostic of the Snyder Hill formation, and suggests placing the base of this

[3] Frank C. Schrader, "Mineral Deposits of the Santa Rita and Patagonia Mountains, Arizona," *U. S. Geol. Survey Bull. 582* (1915).

[4] Herbert Alberding, "The Geology of the Northern Empire Mountains, Arizona," *Univ. Arizona Ph. D. thesis* (manuscript, 1938).
Carl O. Alexis, "The Geology of the Lead Mountain Area, Pima County, Arizona," *ibid., M.S. thesis* (manuscript, 1939).
G. P. Sopp, "Geology of the Montana Mine Area, Empire Mountains, Arizona," *ibid., M.S. thesis* (manuscript, 1940).
F. W. Galbraith, unpublished material kindly made available (1947).

[5] Wayne E. Kartchner, "The Geology and Ore Deposits of a Portion of the Harshaw District, Patagonia Mountains, Arizona," *Univ. Arizona Ph.D. thesis* (manuscript, 1944).

[6] Frank C. Schrader, *op. cit.*, pp. 70–75.

[7] A. A. Stoyanow, personal communication (1947).

EXPLANATION

Sedimentary Rocks

QUATERNARY

Qal — QUATERNARY ALLUVIUM
Terraced gravels, valley fill, soil

Qtv — TRAVERTINE
Late Pleistocene gastropod fauna

TERTIARY

Tf — FANGLOMERATE
Angular fragments, locally derived, usually well cemented

CRETACEOUS(?)

Kcr — CANELO REDBEDS
Post-Permian, probably Cretaceous, sandstones, shales, conglomerates, quartzites, thin-bedded limestones

Ksc — SANDSTONES & CONGLOMERATES
Brown & gray; granite & lava fragments

PERMIAN

Psh — SNYDER HILL LIMESTONE
Snyder Hill fauna; may include Chiricahua ls. Overthrust on redbeds and lavas

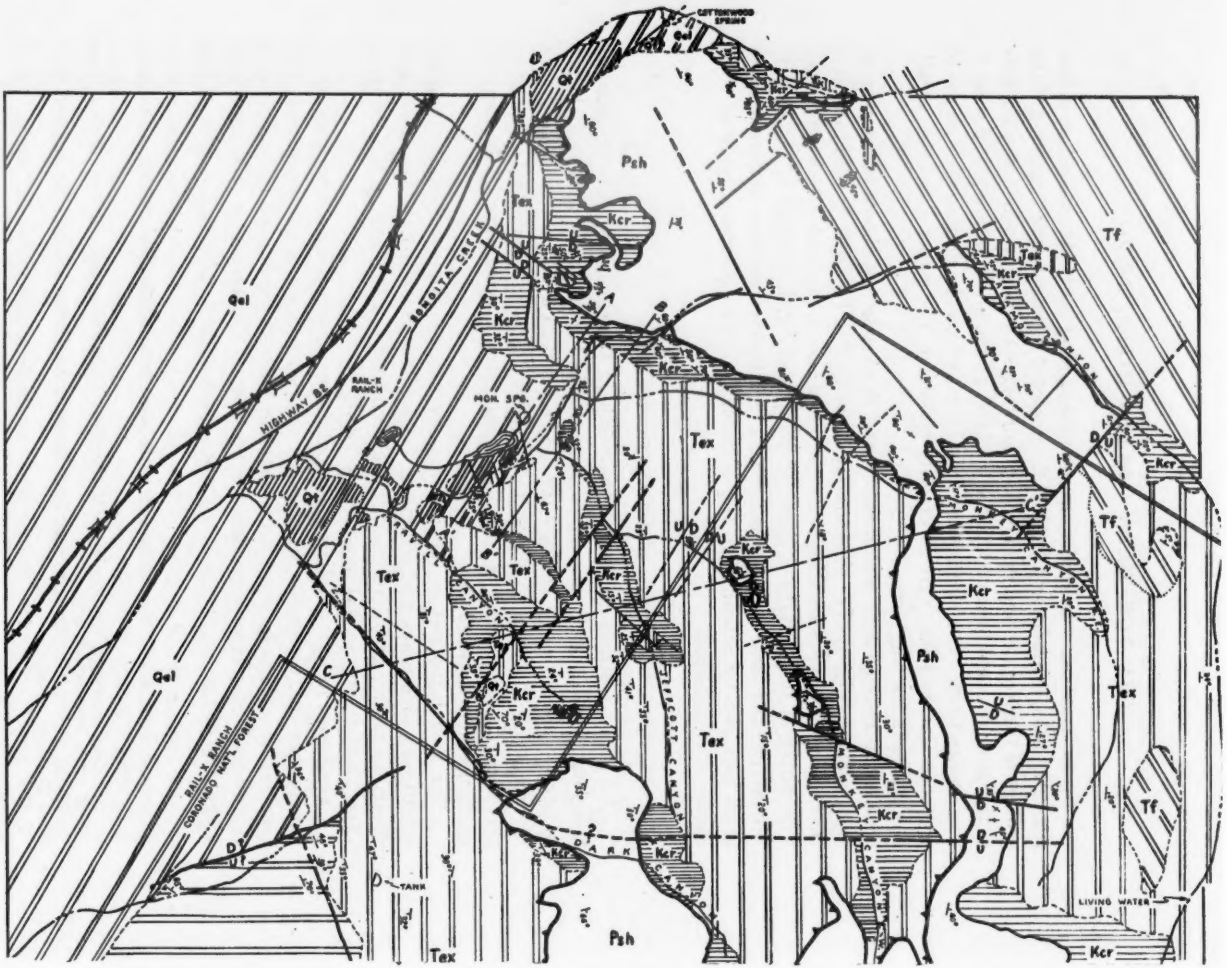
Igneous Rocks

TERTIARY(?)

Td — DIABASE
Single heavy sill, typical texture

Tex — EXTRUSIVE COMPLEX
Red, gray, brown rhyolites, tuffs, andesites, Late Cretaceous or Tertiary

t — INTRUSIVE RHYOLITE
White rhyolite intruding Cretaceous (?) sediments



White rhyolite intruding Cretaceous (?) sediments

Symbols

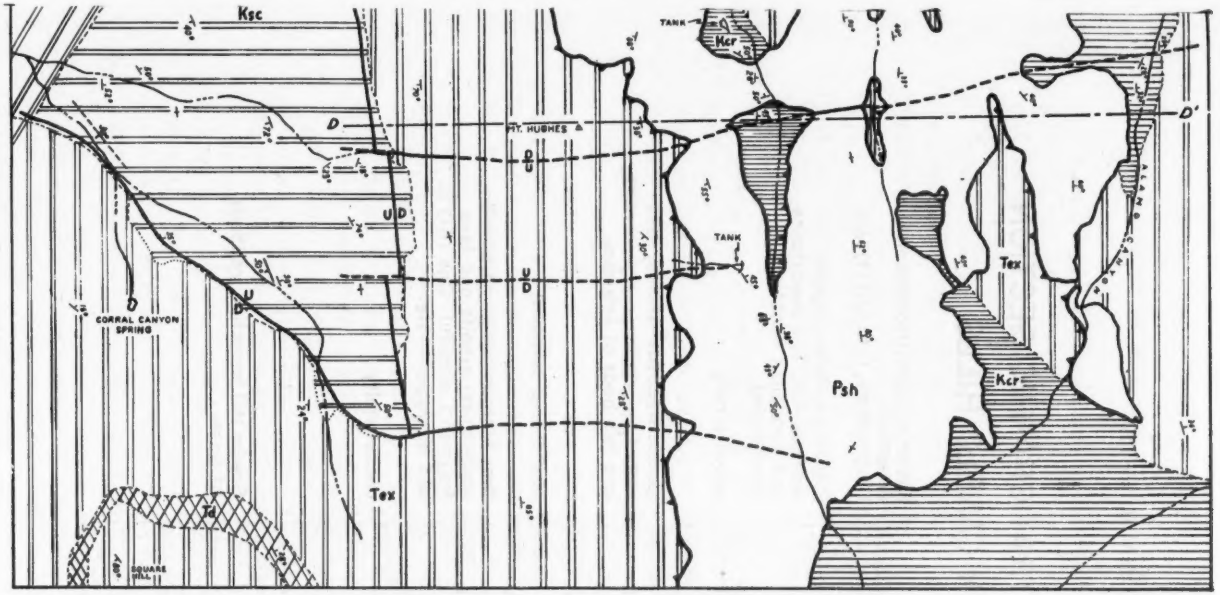
FRONT OF OVERTHRUST

FAULTS
Displacement > 50ft. Dashed are assumed

FAULTS
Displacement < 50ft.

CONCEALED FAULTS

26° STRIKE & DIP



AREAL GEOLOGY OF NORTHERN CANELO HILLS, SANTA CRUZ COUNTY, ARIZONA

TOPOGRAPHY: U.S.G.S., U.S. ARMY, U.S.F.S.
GEOLOGY: J.H. FETH, 1945-1946
SCALE:

DATUM MEAN SEA LEVEL

0 1/2 1
SCALE OF MILES

FIG. 1

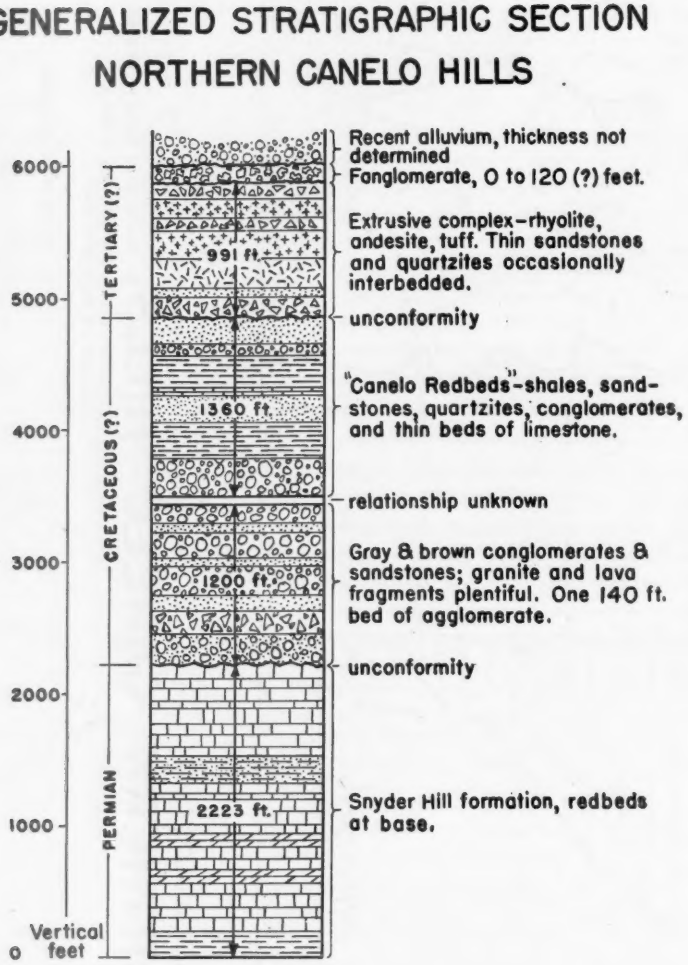


FIG. 2

formation at the bottom of the lowest bed containing *Camerophoria deloi* in the Canelo Hills section.

About 100 feet higher in the section is a thin unit with pockets containing numerous spines of *Archaeocidaris* and fragments of crinoid stems, the latter all less than $\frac{1}{2}$ inch in diameter.

Above this unit are 500 feet of non-fossiliferous strata made up of sandstone, dolomite, and limestone. At the top of these are 156 feet of red shaly sandstone and arenaceous limestone, with a basal bed, 20 feet thick, of hard thin-bedded yellow limestone.

Next above is a thick limestone sequence in which the Snyder Hill fauna is well developed. Here *Dictyoclostus bassi*, *D. occidentalis*, and the horn coral, *Lophophyllum*, make their first appearance.

Figure 3 shows a superficial resemblance between the lowest 700 feet of strata which include about 500 feet of interbedded sandstone, limestone, and dolomite, and the next higher 700 feet (above base) which also show interbedded clastics and limestones. Fossiliferous limestones occur above these. The pattern is suggestive of repetition by faulting.

However, significant differences in the order and character of the thin-bedded units between the lower 500 feet and the 500 feet lying above the first fossiliferous zone lead to the conclusion that the sequence is continuous, not repeated. Also, differences between the fossils in the lowest fossil zone and those in the second fossil zone about 1,200 feet up in the section (see bed 50 in the description of measured section) seem to support this conclusion.

An explanation alternative to faulting, for the apparent repetition of beds, is that the basin of deposition had cycles of accumulation. Limestone, dolomite, and sandstone were deposited alternately as conditions fluctuated from extremes of flooding to extremes of drainage or desiccation. The presence of clastic sediments and dolomites interbedded with limestone suggests that a lagoonal environment prevailed during part of the period of accumulation. During the deoposition of the lower 1,200 feet of the section there appears to have been only one period when the sea provided normal ocean salinity, permitting the area to support a significant assemblage of invertebrates, with brachiopods the dominant form.

The upper 1,000 feet seem to represent a time during which normal marine waters capable of supporting an abundant fauna of considerable variety covered the area. Short interruptions are marked by relatively thin beds of sandstone or arenaceous limestone.

The top of the Canelo Hills section has been removed by recent erosion. The upper 50 feet, however, show a marked change in fauna, gastropods of the *Bellerophon*, *Euomphalus*, and *Murchisonia* types dominating. Furthermore, the limestone shows a higher magnesium content, partly removed strata (not included in the section) being dolomite.

Figure 3 shows an attempt to correlate the Snyder Hill formation of northern Canelo Hills with that in two other localities. These are the Empire Mountains, 20 miles north of the Canelo Hills, and Snyder's Hill on the Tucson-Ajo road about 10 miles southwest of Tucson where the type section is located. The close resemblance of the fauna of the type section to the faunas of the higher beds in both the Empire Mountains and the Canelo Hills is marked. The continuation of a bedded chert about 2 feet thick in both the Snyder's Hill and the Canelo Hills

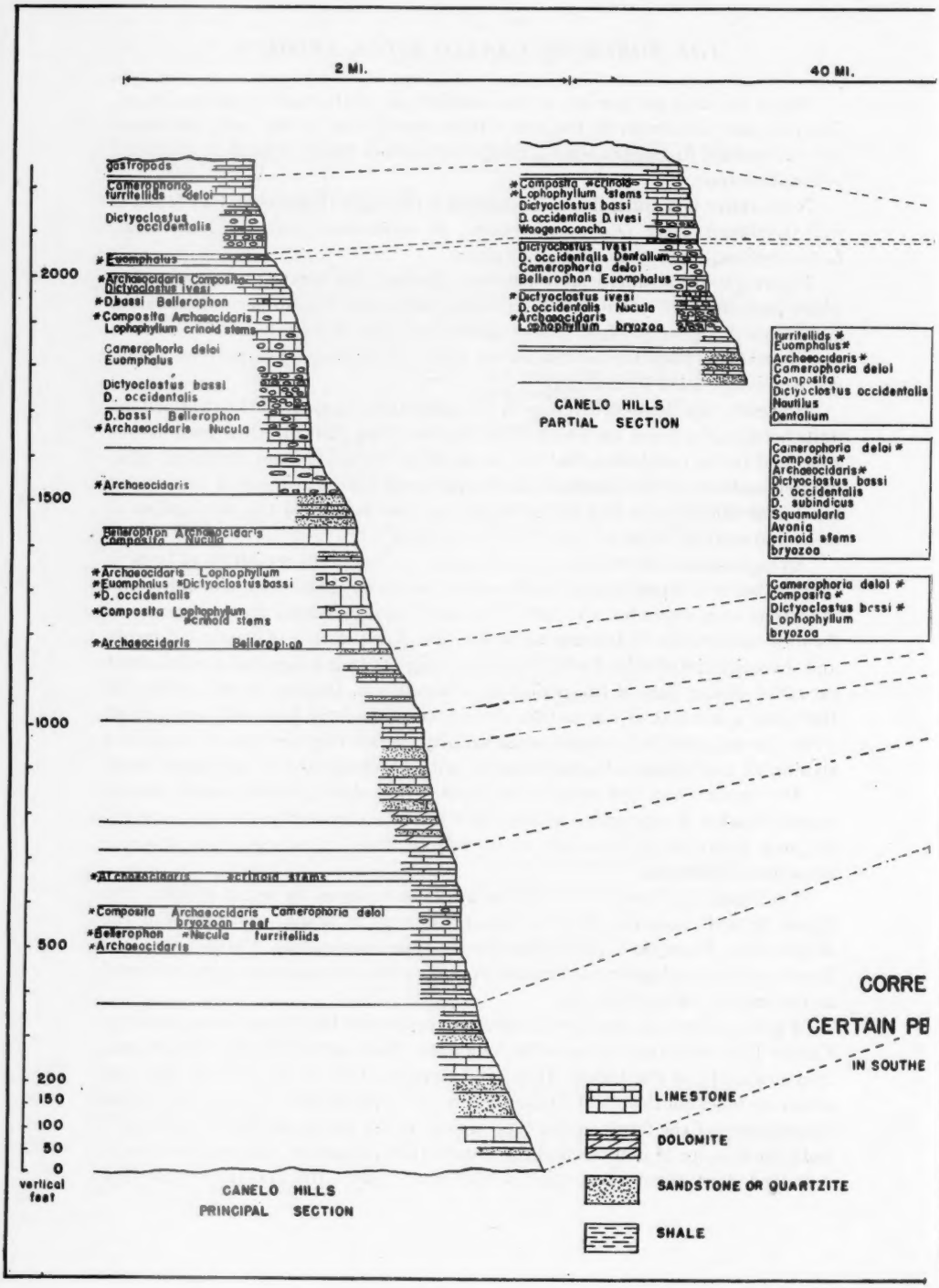
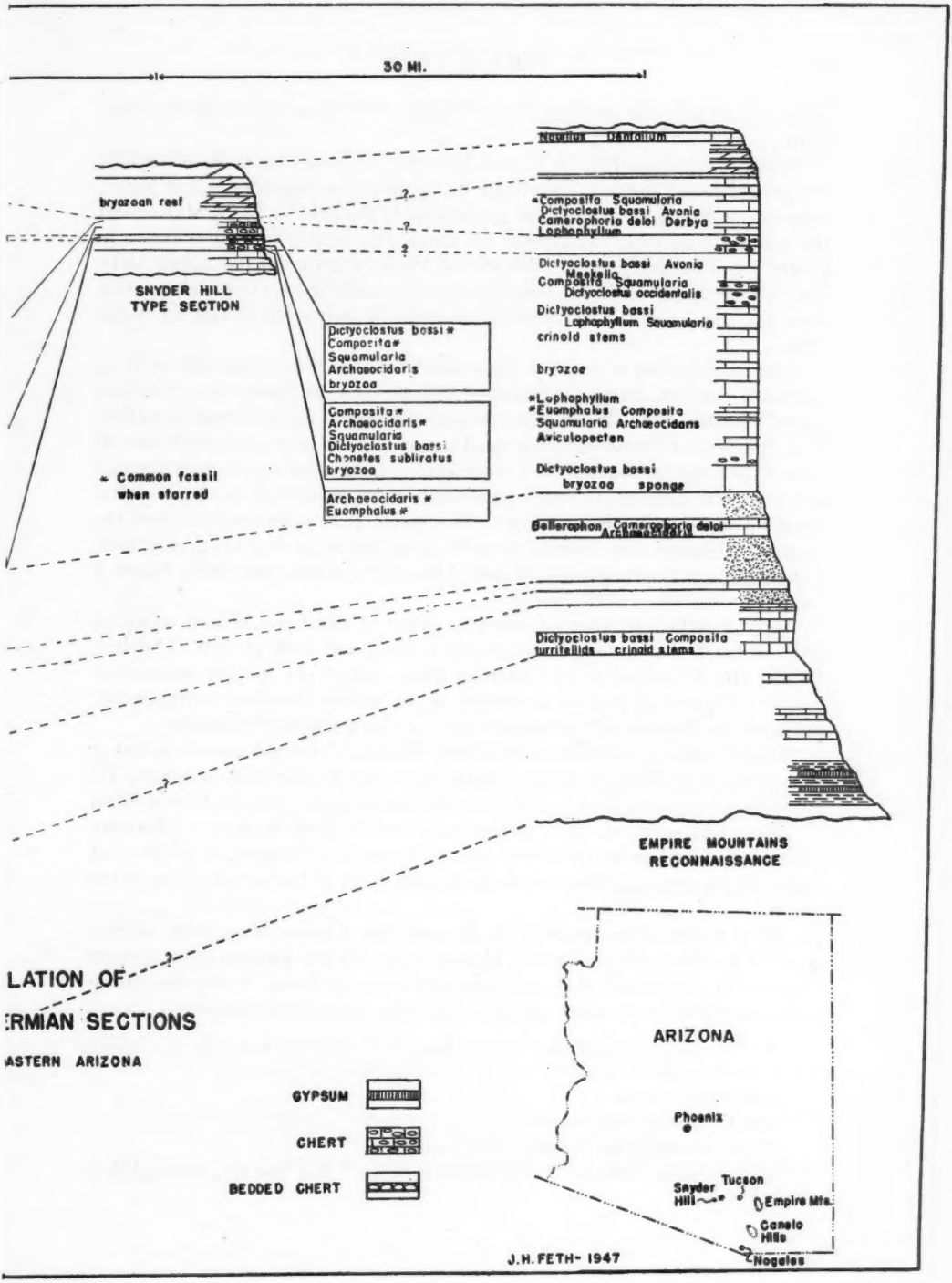

2 MI.
40 MI.
gastropods
Camerophoria
turritellids
delai
Dictyoclostus occidentalis
Euomphalus
2000
Archaeocidaris Composita
Dictyoclostus ivesi
D.bassi Bellerophon
Composita Archaeocidaris
Lophophyllum crinoid stems
Camerophoria delai
Euomphalus
Dictyoclostus bassi
D. occidentalis
D.bassi Bellerophon
Archaeocidaris Nucula
Archaeocidaris
1500
Bellerophon Archaeocidaris
Composita Nucula
Archaeocidaris Lophophyllum
Euomphalus Dictyoclostus bassi
D. occidentalis
Composita Lophophyllum
crinoid stems
Archaeocidaris Bellerophon
1000
Archaeocidaris crinoid stems
Composita Archaeocidaris Camerophoria delai
bryozoan reef
Bellerophon Nucula turritellids
Archaeocidaris
500
200
150
100
50
0
vertical feet
CANELO HILLS
PRINCIPAL SECTION
Composita crinoids
Lophophyllum stems
Dictyoclostus bassi
D. occidentalis D. ivesi
Waagenoconcha
Dictyoclostus ivesi
D. occidentalis Dentalium
Camerophoria delai
Bellerophon Euomphalus
Dictyoclostus ivesi
D. occidentalis Nucula
Archaeocidaris
Lophophyllum bryozoa
CANELO HILLS
PARTIAL SECTION
turritellids
Euomphalus
Archaeocidaris
Camerophoria delai
Composita
Dictyoclostus occidentalis
Nautilus
Dentalium
Camerophoria delai
Composita
Archaeocidaris
Dictyoclostus bassi
D. occidentalis
D. subindicus
Squamularia
Avonia
crinoid stems
bryozoa
Camerophoria delai
Composita
Dictyoclostus bassi
Lophophyllum
bryozoa
CORRE
CERTAIN PE
IN SOUTHE
LIMESTONE
DOLOMITE
SANDSTONE OR QUARTZITE
SHALE

FIG. 3


30 MI.
bryozoan reef
SNYDER HILL
TYPE SECTION
Dictyoclostus bassi *
Composita *
Squamularia
Archaeocidaris
bryozoa
Composita *
Archaeocidaris *
Squamularia
Dictyoclostus bassi
Chonetes subliratus
bryozoa
Archaeocidaris *
Euomphalus *
* Common fossil
when starred
*Composita Squamularia
Dictyoclostus bassi Avonia
Camerophoria deloi Derbya
Lophophyllum
Dictyoclostus bassi Avonia
Meekella
Composita Squamularia
Dictyoclostus occidentalis
Dictyoclostus bassi
Lophophyllum Squamularia
crinoid stems
bryozoe
*Lophophyllum
*Euomphalus Composita
Squamularia Archaeocidaris
Aviculopecten
Dictyoclostus bassi
bryozoa sponge
Bellerophon Camerophoria deloi
Archaeocidaris
Dictyoclostus bassi Composita
turritellids crinoid stems
EMPIRE MOUNTAINS
RECONNAISSANCE
LATION OF
ERMIAN SECTIONS
ASTERN ARIZONA
GYPSUM
CHERT
BEDDED CHERT
ARIZONA
Phoenix
Snyder Hill
Tucson
Empire Mts.
Canelo Hills
Nogales
J.H. FETH- 1947

areas and its probable presence in the Empire Mountains section is also noteworthy.

The section for the Empire Mountains is based on work by F. W. Galbraith, not yet published but made available for comparative purposes in this paper, supplemented by a reconnaissance undertaken in the field by E. D. McKee and the writer during which zonation of the fauna was roughly plotted as shown in Figure 3. In the Empire Mountains section, the uppermost 800 feet appear to be unquestionably Snyder Hill. Below that are approximately 250 feet of alternating quartzite and limestone beds containing fossils in the upper of two limestone units.

One hundred feet of massive limestone below the lowest quartzite hold an equivocal position. Stoyanow[8] has referred to these as "beds with Manzano fauna." Small gastropods and pelecypods are distinctive of the assemblage. However, the recent reconnaissance revealed the presence of large productids, seen in cross section and unidentifiable. The presence of these large brachiopods suggests a Snyder Hill affinity. It seems reasonable, then, to extend the base of the Snyder Hill formation in the Empire Mountains at least to the bottom of the lowest fossiliferous zone. Correlation of the basal 500 feet of strata in the northern Canelo Hills with strata in the Empire Mountains remains indefinite. Figure 3 suggest possibilities in this respect.

Sopp[9] mentions between 1,450 and 2,150 feet of limestones, dolomites, marls, red and black shales, conglomerates, sandstones, and some gypsum below the Snyder Hill formation in the Montana Mine area of the Empire Mountains. Figure 3 shows that gypsum is present in the section examined during reconnaissance by McKee and the writer in the northern Empire Mountains.

Alexis[10] working in the southern Empire Mountains, found 1,400–2,200 feet of limestone, quartzite, and silicified shale below the Snyder Hill formation. He recorded no gypsum. No gypsum has been found in the northern Canelo Hills.

Galbraith[11] confirms Alexis' observation that no gypsum occurs in Permian strata below the Snyder Hill formation in the southern Empire Mountains, but states that gypsum is present in many Permian beds of the northern part of the range.

These relationships, gypsum in the northern Empire Mountains, and no gypsum in the southern Empire Mountains, or in the Canelo Hills, support Stoyanow's conclusion[12] that a Permian seaway existed with its shoreline somewhere north of Tucson, and a trough deepening toward the southeast.

[8] A. A. Stoyanow, "Correlation of Arizona Paleozoic Formations," *Bull. Geol. Soc. America*, Vol. 47 (1936), p. 530.

[9] G. P. Sopp, *op. cit.*, p. 17.

[10] Carl O. Alexis, *op. cit.*, pp. 8–10.

[11] F. W. Galbraith, personal communication (1947).

[12] A. A. Stoyanow, "Paleozoic Paleogeography of Arizona," *Bull. Geol. Soc. America*, Vol. 53 (1942), Pl. 5.

It seems probable that further stratigraphic study in the region will demonstrate that the redbeds, marl, gypsum, dolomite, and limestone known to underlie limestones with Snyder Hill fauna represent an earlier phase of a continuous deposition and should be included within the formation. However, at present, no sharp lower limit of the Snyder Hill formation can be drawn.

Table I "Comparison of Brachiopoda," is a tabulation of forms of the northern Canelo Hills which are found also in the Kaibab limestone (Arizona Plateau region) as reported by McKee[13], and in the Lower and Middle Permian strata of the Glass Mountains, Texas, as listed by R. E. King.[14]

TABLE I

COMPARISON OF BRACHIOPODA

	Canelo Hills	*Kaibab*	*Glass Mountains*		
			Wolfcamp	*Leonard*[1]	*Word*
Meekella sp.	P*	P	R*	P	
Dictyoclostus bassi McKee[2]	A*	A		A	
D. ivesi	P	A			
D. occidentalis	A	A		A	P
Waagenoconcha montpelierensis	R	P	R	P	P
Marginifera opimus (?)	P	P		P	A
Camerophoria deloi King[3]	A	?		?	R
Pugnoides pinguis	?	P		P	R
Squamularia guadelupensis	P	A	P	A	P
Hustedia sp.	R	P	?	P	P
Composita sp.[4]	A	A		P	

* A—abundant; P—present; R—rare.

[1] Tabulation under Leonard includes forms originally listed within the Hess, following redefinition of the Leonard of Glass Mountains by P. B. King in *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 4 (April, 1942), p. 651.

[2] This is "*Productus* (*Dictyoclostus*) *bassi* McKee," of McKee, and is included within the "*Productus ivesi*" of R. E. King.

[3] Field distinction between *Camerophoria deloi* and other pugnoids is impossible. The tabulation follows Stoyanow's identification of *Camerophoria deloi* as the common pugnoid of the Snyder Hill formation. Since neither occurs in the Wolfcamp, and both are rare in the Word, the distinction is not here considered important.

[4] No distinction among *Composita mexicana*, *C. subtilita*, or *C. arizonica* McKee has been attempted in the Canelo Hills collection; nor for comparative purposes, in this tabulation, is it necessary.

The similarity of brachiopod fauna in the Snyder Hill limestone of the Canelo Hills and in both the Kaibab and Leonard formations is noteworthy. Although neither cephalopods nor fusulinids, normally used in Permian correlation, have been found in northern Canelo Hills, nevertheless, there seems to be little room for doubt that the beds here are essentially equivalent in time to the Leonard formation of lower Middle Permian age in Texas. They appear likewise to be equivalent to the Kaibab limestone of northern Arizona and southern Utah.

The presence of *Dictyoclostus bassi* in the San Andres formation, reported by

[13] E. D. McKee, "Environment and History of the Toroweap and Kaibab Formations of Northern Arizona and Southern Utah," *Carnegie Inst. Pub. 492* (1938), tabulation, p. 170.

[14] Robert E. King, "The Geology of the Glass Mountains, Texas," Pt. II, *Univ. Texas Bull. 3042* (1930), pp. 147–50.

Skinner[14a] suggests that the Snyder Hill formation may extend upward to a partial time equivalency with the Word. Basing the correlation on the complete brachiopod assemblage rather than on individual forms, however, appears to put the weight of evidence in favor of a Leonard time equivalency for the Snyder Hill.

The entire Permian section measured in the northern Canelo Hills appears to represent deposition under fluctuating sea and land conditions with changing depth of water, salinity, and height of adjacent land areas. This suggests that the Snyder Hill formation may have to be redefined to include the entire 2,223 feet measured in the northern Canelo Hills and such additional strata as may ultimately be found in a section even more completely preserved. In any event, the formation must be extended far beyond the limits of the 226½ feet of the type section, which actually embraces only the uppermost known beds of the formation.

MEASURED SECTION

SNYDER HILL FORMATION, NORTHERN CANELO HILLS, EAST OF ALAMO GORGE, NE. ¼, SEC. 4, T. 20 S., R. 16 E.

TERTIARY: Fanglomerate (unnamed)

Unconformity

PERMIAN: Snyder Hill formation

Strike N. 10° W.; dip 70° NE.

	Thickness in Feet
67. Limestone: dark gray; weathers to dark gray commonly smooth surface; aphanitic to fine, uniform grain; cliff-forming; beds about 2 ft.; small calcite blebs throughout unit; calcified cross sections of large productids not common; topmost bed contains areas in which shell fragments are plentiful, among them some recognizable gastropods, small bellerophontids, *Euomphalus*, small turritellids (possibly *Murchisonia*)	29
66. Limestone: red; weathers to distinctive rusty red surface deeply pitted, but some areas weather smooth, gray, or red; generally granular, but some areas aphanitic and exceptionally hard; cliff-forming	4
65. Limestone: gray, red, brownish gray, with true gray most common; weathers to gray rough (but not raspy)[15] surface; except for redbeds which show pink granular surface; few chert nodules irregularly cylindrical, 2–4 in. diameter; top half of unit contains calcified brachiopod cross sections, small bellerophontids; bottom half contains reef of chain-type bryozoans near base, *Camerophoria deloi**,[16] *Dictyoclostus occidentalis*, *D. bassi*, *D. ivesi*, *Pugnoides bidentalis*, *Composita* sp.*, *Nucula* sp., *Archaeocidaris;* fossils highly silicified, some occur in chert nodules	60
64. Partly concealed but mostly limestone: gray, red, brownish gray; weathers gray to light gray to smooth surfaces; granular; slope-forming; beds probably 1 to 10 or 20 ft.; chert moderately common in nodules irregularly cylindrical, diameter 2–4 in.; one nodule observed contained fossil, probably *Dictyoclostus occidentalis*	52
63. Limestone: gray to brownish gray; weathers to gray, smooth surfaces; very fine, uniform grain to moderately granular; cliff-forming; lichen-covered chert characterizes this unit, occurring in boulders 1–3 ft. in diameter, chert composing 25–75 per cent of rock in some areas as highly irregular, rough-weathering blebs and nodules, some 6×12 in.; chert weathers light rust color to nearly black	25

[14a] John W. Skinner, "Correlation of Permian of West Texas and Southeast New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 11 (November, 1946), pp. 1857–74.

[15] See Figure 4, photograph of a raspy weathering surface in dolomitic limestone.

[16] Throughout descriptions of measured sections in this paper, forms plentiful within each unit are marked with asterisk (*).

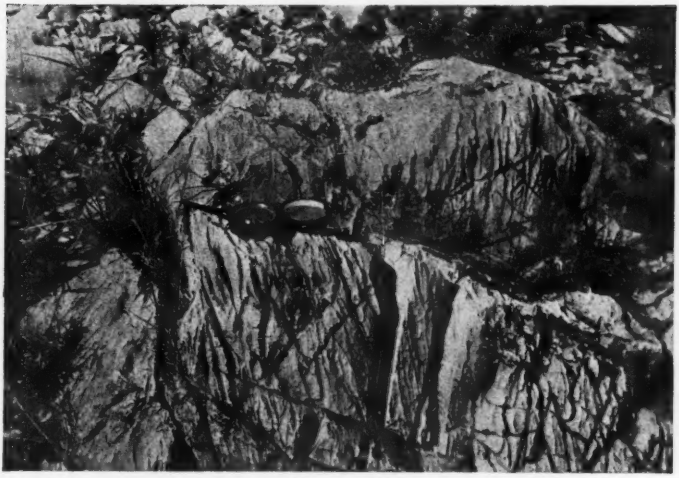


FIG. 4.—Photograph of surface of bed of limestone illustrating weathering texture described as raspy in this paper.

	Thickness in Feet
62. Limestone: reddish brown; weathers to pinkish gray; fairly smooth surfaces; moderately granular; weakly cliff-forming; beds ½–1 ft.; characterized by shape of chert inclusions which are exceptionally long and thin, ½×12 in. being common; stubby chert 2×4 in. also occurs; long nodules, some showing hard core, pencil-diameter, standing partly above weathered surface of main nodule; all chert in this unit weathers to smooth dark rust color, with no lichens	15
61. Partly concealed: two limestones occur in discontinuous outcrops; one is brownish gray, weathering to light gray, moderately raspy surface; fine-grained; other is red, weathering to red or rusty smooth surfaces; coarse-grained; both are slope-forming; upper 2 ft. of unit highly cherty, appearing almost bedded; chert light gray, weathering to light rusty brown	15
60. Limestone: gray, some beds tinged with brown; weathers to gray irregular surface; fine uniform grain; cliff-forming; beds about 2 ft.; 3 ft. from top of unit is band of bedded chert 6 in. thick (this may be silicification along bedding-plane fault); unit contains three large bellerophontids and scattering of unrecognizable shell fragments	23
59. Mostly concealed; contains beds of limestone, light to very dark gray; weathers gray or very light gray, smooth to raspy surfaces; lighter-colored beds are granular, darker are aphanitic, one with distinct fetid odor; slope-forming; bedding poorly expressed	27
58. Limestone: gray; weathers to gray smooth or moderately raspy surfaces; fine-grained to moderately granular; mainly slope-forming; thin-bedded; top 6 ft. contain: large bellerophontids, *Euomphalus**, small turritellids, *Dictyoclostus ivesi*, *Composita* sp.; fossils most common in single bed made up nearly 50 per cent of poorly preserved spines of *Archaeocidaris*	40
57. Limestone: gray to dark gray; weathers to smooth or pitted surfaces, same colors; moderately granular with numerous calcite veinlets; cliff-forming; beds 1–6 ft.; chert nodules variable in size, not common; fossils include: in basal part; *Dictyoclostus bassi*, *D. occidentalis*, *Camerophoria deloi*, small turritellids; in middle ¾ of unit; crinoid stems*, horn coral (*Lophophyllum* identified)*, *Composita* sp.*, large productid, smaller productids, *Archaeocidaris* spines; in topmost 10 ft.; large brachiopods (cross sections), bellerophontids	174

	Thickness in Feet
56. Limestone: brownish gray; weathers to gray, raspy or irregularly pitted surfaces; medium-grained, calcite veinlets common; cliff-forming; probably massive; chert very plentiful in this member occurring in blebs, interlocking veins, and large and small nodules commonly rusty red on surface; fossils, not plentiful, include: bellerophontids, *Nucula* sp., *Archaeocidaris* spines and plates locally abundant near top of unit, and other fragments unidentified	85
55. Limestone: gray or brownish gray; weathers to gray and light gray moderately raspy surfaces; cliff-forming; beds poorly expressed (may be somewhat shattered); at base of member is 4 ft. bed of arenaceous purple limestone containing 3 in. calcite vein, crystalline, but not continuous	83
(Strike changes to N. 40° W., dip 50°–60° NE., probably by slip along bedding planes)	
54. Partly concealed, mainly limestone: gray to brown tinged with red; weathers to light gray surface, raspy at base of member, smoother toward top: arenaceous, somewhat granular; slope-forming; beds range to 10 ft.; small chert nodules common in basal part, larger nodules 6–8 in. long occur toward middle; *Archaeocidaris* spines common in two beds about 25 ft. from base, no other fossils identifiable; at 55 ft. occurs bed of purplish arenaceous limestone showing marked cross-lamination, laminae fraction of inch to 3 in., thicker ones marked by chert or composed of chert; outcrop is discontinuous	105
53. Sandstone, quartzite, arenaceous limestone: light gray, some beds speckled with hematitic stains; weathers to rusty tan or reddish gray smooth surfaces, tan dominating float material; uniformly fine grain, lime, silica, hematite content variable; slope-forming; bedding not expressed	75
52. Limestone: gray and brownish gray; weathers to gray pitted surfaces; moderately granular; cliff-forming; beds 2–6 ft.; irregular cherty nodules range to 2×6 in., but are not common; occasional fossils include: bellerophontids, *Archaeocidaris* spines; *Composita* sp., *Nucula* sp.	40
51. Concealed: probably mostly limestone; bedding not expressed except for discontinuous outcrops of sandy limestone 3–12 in. thick	46
50. Limestone: gray and brownish gray; weathers to smooth gray surfaces; partly arenaceous, moderately granular, cut by numerous paper-thin calcite veinlets; slope-forming; bedding poorly expressed; not generally cherty; basal 20–30 ft. include: *Archaeocidaris* spines, small turritellids, large bellerophontids, brachiopod cross sections; small crinoid stems*; zone near middle of unit includes: large crinoid stems*, horn coral, *Composita* sp.*; upper half of member includes; *Dictyoclostus bassi* (?), *Composita* sp., *Archaeocidaris* spines*, *Dictyoclostus occidentalis*, horn coral, bellerophontids	186
49. Partly concealed: includes beds of limestone, sandstone, arenaceous limestone; slope-forming throughout; basal unit is low ridge of ocher-yellow limestone, thin-bedded, rather hard, 20 ft. thick; above is very soft pink and gray calcareous sandstone; next about 100 ft. of brick red to dark red, calcareous sandstone in shaly layers weathering typically to cubical fragments 1–2 inches across	156
48. Limestone: gray and brown; weathers to tan or light brownish gray smooth surfaces; fine-grained, some beds arenaceous; slope-forming; beds 1–6 ft.; one thin bed 6 ft. from top of member shows laminae $\frac{1}{16}$ to $\frac{1}{4}$ in. standing out on weathered gray surface	29
47. Sandstone: red and yellow; weathers to red or rusty smooth surfaces; fine-grained; very slightly calcareous; slope-forming; single bed; laminae $\frac{1}{2}$–3 in.	9
46. Limestone: gray, some beds speckled red; weathers to light dusty gray raspy surfaces; fine-grained to moderately granular, everywhere appears muddy; cliff-forming; beds 2 ft.	20
45. Sandstone: tan; weathers to light yellow-gray smooth surfaces; fine-grained; slope-forming, probably thin-bedded	32
44. Limestone: brownish gray; weathers to medium gray; moderately granular; cliff-forming; beds 1–3 ft.; near top, siliceous geodes $\frac{1}{2}$–1 in. diameter are common; one bed about 1 ft. thick is very coarsely granular limestone, mottled red, white, gray	12
43. Sandstone: light gray; weathers to light gray smooth surfaces with tinges of rust and pink; fine-grained; slope-forming; beds 6 in.; becomes calcareous toward top	22
42. Limestone: gray with patches of red and brown; weathers to gray raspy surface; fine- to coarse-grained; cliff-forming; beds 8 in. to 2 ft.	13

		Thickness in Feet
41.	Sandstone: like unit 45 but shows pronounced pitting, pits being stained with limonite	21
40.	Dolomite: dark muddy gray; weathers to dusty gray raspy surface; fine-grained; slope-forming; beds 6 in. to 1 ft.	12
39.	Sandstone: like unit 43 but only moderately calcareous	24
38.	Dolomite: dark gray; weathers to gray raspy surfaces; fine-grained; cliff-forming; beds 1–2 ft.; includes many small irregularly rounded silica geodes; topmost 4 ft. show small crinoid stems and *Archaeocidaris* spines common in local pockets	8
37.	Concealed	16
36.	Dolomite: like unit 38 but coarser-grained	20
35.	Sandstone: light gray; weathers to rusty tan smooth surfaces; slope-forming; bedding not expressed	12
34.	Dolomite: dark gray; weathers to gray slightly raspy surfaces; fine-grained; cliff-forming; beds about 2 ft.; irregular chert nodules and partings	16
33.	Dolomite: purplish brown; weathers to light purple smooth surface; highly arenaceous, fine-grained; slope-forming; bedding obscure; topmost 2 in. of spongy rust-colored chert	4
32.	Limestone: medium gray; weathers to light gray smooth surfaces; fine-grained; slope-forming; beds 6 in. to 1 ft. thin red or brown cherty partings occur	6
31.	Limestone: dark gray; weathers to dark gray very raspy surface; criss-crossed by calcite veinlets dividing rock into small irregular chunks; cliff-forming; beds 2–3 ft.; small cherty nodules, not common	5
30.	Limestone: gray; weathers to gray rough surfaces; medium- to fine-grained; cliff-forming; beds 6 in. to 3 ft.; one bed near middle of unit contains a few *Archaeocidaris* spines	27
29.	Limestone: dark gray; weathers to gray moderately raspy surfaces; medium-grained; cliff-forming; beds 1–3 ft.	8
28.	Dolomite: dark gray; weathers to medium gray slightly pitted surfaces; fine-grained; slope-forming; beds 6 in. to 1 ft.	6
27.	Sandstone: like unit 35	7
26.	Limestone: dark gray; weathers to yellow-gray raspy surfaces; moderately granular; cliff-forming; beds 1–4 ft.; rough cherty nodules about 4 in. diameter common; lower 4 ft. contain pockets in which *Archaeocidaris* spines and crinoid stems less than ½ in. diameter are locally abundant	16
25.	Limestone: pink with red specks; weathers to pinkish gray smooth surfaces; arenaceous; slope-forming; beds 6 in. to 1 ft.	6
24.	Limestone: dark gray; weathers to light gray raspy surfaces; fine-grained; slope-formnig; single bed; thin white calcite veinlets common	4
23.	Limestone: like unit 25	12
22.	Limestone: like unit 24	13
21.	Concealed: probably highly calcareous brick red siltstone, weathering to shaly slabs less less than ½ in. thick	9
20.	Limestone: medium gray; weathers to gray lightly pitted surfaces; medium-grained, includes small white grains; slope-forming; beds about 2 ft.	11
19.	Limestone: brown; weathers to light gray smooth surfaces; medium- to fine-grained; cliff-forming; beds 1–10 ft.; chert plentiful, in nodules up to 15 in. long near bottom of unit, one bed near middle of unit made up about 50 per cent of chert blebs; fossils not common, include: reef of chain-type bryozoans, *Composita* sp., productids (within chert nodules), *Camerophoria deloi*, *Archaeocidaris* spines	45
18.	Limestone: gray with tinges of brown and pink; weathers to light dusty gray smooth surfaces; medium-grained; cliff-forming; beds 2–3 ft.; calcite blebs rimmed with rusty chert are common; fossils include: in bottom 4 ft., *Archaeocidaris* spines*, productids; about 10 ft. higher: *Euomphalus* sp.*, turritellids, *Nucula* sp.*	55
17.	Dolomite: gray; weathers to dusty yellow-gray smooth surfaces; fine-grained; slope-forming; single bed	5
16.	Limestone: dark gray; weathers to olive-gray or dark gray raspy surfaces, smoother toward top of member (probably as Mg-content decreases); fine-grained; slope-forming; beds 1–3 ft.; irregular rounded calcite blebs less than 1 in. diameter common in some beds; lower 50 ft. probably contain thin reddish sandy beds which do not crop out	110
15.	Limestone: gray; weathers to gray smooth surfaces; medium-grained; cliff-forming; beds about 4 ft.; calcite nodules to 4 in. long are common	15
14.	Limestone: gray; weathers to gray and red raspy surfaces; fine-grained; slope-forming; single bed	2

		Thickness in Feet
13.	Limestone: tan; weathers to pinkish gray nobbed surfaces; fine-grained, arenaceous; cliff-forming; single bed	3
12.	Limestone: reddish gray; weathers to gray smooth surface veined with red; fine-grained, arenaceous; cliff-forming; single bed	3
11.	Siltstone: dark brick red; weathers only slightly lighter; slope-forming; bedding obscure; sheets off in flakes $\frac{1}{16}$–$\frac{1}{8}$ in. thick; possibly partly metamorphosed	10
10.	Mostly concealed: probably contains thin-bedded gray limestones, siliceous material grayish white and red	78
9.	Mostly concealed: consists largely of limestone weathering to gray or red chunks 4 in. diameter	40
8.	Limestone: gray; weathers to very rough surfaces mottled gray and red; granular; cliff-forming; beds about 2 ft.; includes areas (fragments?) of black and brown material	10
7.	Sandstone: dark red; weathers to lighter purplish red smooth surfaces; medium-grained; feldspar grains, much decomposed, make up about 20 per cent of rock; beds about 2 ft.; slope-forming; fragments about $\frac{1}{8}$ in. square of dark red baked shale(?) are common	30
6.	Sandstone: like unit 7 but including some beds of yellow sandstone about 1 ft. thick	54
5.	Concealed	24
4.	Limestone: like unit 8 but apparently partly silicified	30
3.	Concealed	8
2.	Sandstone: like unit 7	18
1.	Concealed: apparently red and yellow sandstones, shales, and arenaceous limestones	40
	Total	2,223

Overthrust

TERTIARY(?): Rhyolite

MEASURED SECTION

SNYDER HILL FORMATION, NORTHERN CANELO HILLS, NORTHEASTERNMOST LIMESTONE HILL IN CANELO HILLS, NW. ¼, SEC. 2, T. 20 S., R. 16 E.

(Partial section only)

The rocks above bed No. 10 are composed of shattered limestone, unidentifiable as to bedding. They probably represent a continuation of Snyder Hill strata of indeterminate extent. They are now part of the erosion surface on the dip-slope side of the hill.

PERMIAN: Snyder Hill formation

Strike, N. 10° W., dip 65° NE.

		Thickness in Feet
10.	Limestone: gray to muddy gray; weathers to gray-brown surfaces commonly smooth; fine-grained; weakly cliff-forming; beds 1–2 ft.; some beds less resistant form low narrow "roads" between harder strata	25
9.	Limestone: red; weathers to very roughly pitted surface with occasional areas remaining smooth and reddish gray; aphanitic to granular; strongly cliff-forming	6
8.	Limestone: gray to brownish gray; weathers to gray, pitted surfaces; fine-grained; cliff-forming; beds 1–6 ft.; contains chert nodules to 1 ft. long distinguished from beds below by chert weathering to a much lighter rusty tan; fossils include: small crinoid stems*, horn coral (*Lophophyllum* identified)*, *Archaeocidaris* spines, *Composita* sp.*, *Meekella* sp., *Dictyoclostus bassi*, *D. ivesi*, *D. occidentalis*, *Marginifera* sp.	132
7.	Limestone: reddish gray; weathers to reddish gray fairly smooth surfaces; fine-grained; cliff-forming; characterized by chert in heavy semi-bedded tabular masses up to 8 in. thick but not continuous along strike for more than a few feet at a time	10
6.	Limestone: gray; weathers to gray or light gray rough surfaces; fine-grained; cliff-forming; beds 3–15 ft.; contains chert nodules commonly flattened to about 5×3×1 in., weathering to smooth or sandy, light rusty brown surfaces; fossils partly silicified in limestone or occurring within chert nodules include: various bryozoans, *Dentalium*(?);	

		Thickness in Feet
	small bellerophontids, small turritellids, small crinoid stems, *Composita* sp., *Camerophoria deloi*, *Dictyoclostus ivesi*, *D. occidentalis*	100
5.	Limestone: gray and red; weathers to gray or reddish gray smooth surfaces; fine-grained; cliff-forming; beds 3–4 ft.; contains notably less chert than unit 4 and nodules are smaller; fossils weakly silicified include: *Archaeocidaris** plates and spines especially common in one bed near top of member; small crinoid stems, various bryozoans, horn coral, small bellerophontids, *Composita* sp., *Dictyoclostus bassi*, *D. occidentalis*, *Nucula* sp.	30
4.	Limestone: gray; weathers to gray moderately rough surfaces; fine-grained; cliff-forming; beds 1–6 ft.; characterized by abundant chert which makes up 25–70 per cent of rock surfaces in some beds occurring in irregularly cylindrical nodules 9×6 in. in lower 15 ft., 15×9 in. in upper 40 ft., weathering to dark rusty brown; fossils only in upper 40 ft., include: chain-type bryozoans, *Dictyoclostus bassi**, *D. occidentalis*, other fragmentary brachiopod shells or cross sections	55
3.	Mostly covered: contains limestone beds with chert nodules 1–4 in. long and many cross sections of large productid-type brachiopods	35
2.	Limestone: gray or brownish gray; weathers to gray raspy surfaces; fine-grained; cliff-forming; beds about 1 ft.	6
1.	Sandstone: gray; some beds with hematite or limonite specks on weathered surface; weathers to rusty red smooth surfaces; medium-grained; weakly calcareous; includes a few thin beds of red limestone	72
	Total	471

Measurement discontinued at old C.C.C. road. Other Permian beds underlie unit 1.

MEASURED SECTION

SNYDER HILL FORMATION, EAGLE CLIFF, EMPIRE MOUNTAINS, PIMA COUNTY, ARIZONA

Reconnaissance study with E. D. McKee. Thicknesses are approximate.

PERMIAN: Snyder Hill formation

Strike N. 30° W., dip 35° NE.

Top of sequence is long dip-slope. Uppermost 50–100 feet were not studied.

		Thickness in Feet
29.	Limestone: dark gray; heavy-bedded; fossils include: *Dentalium**, *Nautilis* sp., low-spired gastropods*[17]	25
28.	Dolomite: light gray; heavy-bedded; fossils include: *Archaeocidaris* spines and plates very common in single bed at top of unit	25
27.	Quartzite: brown	12
26.	Dolomite: light gray; heavy-bedded; no fossils noted	35
25.	Sandstone: brown; tightly cemented	8
24.	Dolomite: light gray; thin-bedded; contains bands of quartz; no fossils noted	20
23.	Limestone: black, fetid; fossils include: *Archaeocidaris* spines*, crinoid stems*, *Dictyoclostus occidentalis*	5
22.	Limestone: like unit 23; no fossils noted	35
21.	Limestone: like unit 23; fossils include: *Dictyoclostus occidentalis**, *D. bassi*, *Derbya* sp., *Lophophyllum**	20
20.	Limestone: like unit 23; fossils include: *Composita* sp.* (small), *Composita* sp. (large), *Avonia* sp., *Squamularia* sp., *Camerophoria deloi*, bryozoans (branching type)	25
19.	Limestone: like unit 23; fossils include: *Dictyoclostus occidentalis*, *Composita* sp., large crinoid stems	25
18.	Limestone: like unit 23; contains many chert concretions; no fossils noted	15
17.	Limestone: like unit 23; fossils include: *Dictyoclostus bassi*, *D. occidentalis*, *Meekella* sp., *Squamularia* sp., *Avonia* sp., *Composita* sp.	50

[17] As in other measured sections in this paper, the asterisk (*) denotes fossils common in the bed being described.

	Thickness in Feet
16. Limestone: like unit 23; abundant small chert concretions; no fossils noted	20
15. Limestone: like unit 23; fossils include: *Dictyoclostus bassi**, crinoid stems*, bryozoans*, *Lophophyllum*, *Squamularia* sp.	175
14. Limestone: like unit 23; *Lophophyllum* abundant	25
13. Limestone: like unit 23; fossils include: *Euomphalus**, *Squamularia* sp., *Aviculopecten*	50
12. Limestone: like unit 23; fossils include: *Composita* sp., *Archaeocidaris* spines	200
11. Limestone: like unit 23; thick concentration of black flint concretions	5
10. Limestone: like unit 23; fossils include: *Dictyoclostus bassi**, cylindrical bryozoans*, "Kaibab sponge"	25
9. Quartzite: brown and tan	35
8. Limestone: two beds light gray, separated by one of black; latter contains: *Bellerophon* sp., *Archaeocidaris* spines, *Camerophoria deloi*, unidentified productids	20
7. Quartzite: brown and tan	80
6. Limestone: dark gray; massive	12
5. Sandstone: weak red to yellow; fine-grained; slope-forming	30
4. Limestone: light gray; massive; cliff-forming	15
3. Limestone: light gray; thin-bedded; slope-forming	15
2. Limestone: light gray; massive; magnesian; cliff-forming	40
1. Limestone: dark gray; massive; cliff-forming; fossils include: *Composita* sp., *Dictyoclostus iwesi*, crinoid stems	50
Total	917

Lower strata of Permian at base, including marls, limestones, gypsum, shales.

MEASURED SECTION

SNYDER HILL FORMATION (TYPE LOCALITY), SNYDER'S HILL,
PIMA COUNTY, ARIZONA

Measured with E. D. McKee

QUATERNARY: Unconsolidated valley fill

Unconformity

PERMIAN: Snyder hill formation

Strike N. 45° W.; dips: 55° NE., bed No. 10;
32° NE., beds 9-4; 28° NE., beds 3-1

	Thickness in Feet
10. Dolomite: gray to yellowish gray; coarsely granular; weathers to exceptionally raspy surfaces, gray; beds 2–4 ft.; grains sparkle brightly; cut by many calcite veins	20.0
9. Dolomite: gray; weathers to creamy gray, light gray, or brown; fine-grained; beds ½–1 ft.; slope-forming	35.0
8. Dolomite: dark gray; weathers to dark gray moderately rough surfaces; massive; forms distinct cliff	4.0
7. Dolomite: gray; weathers to buff moderately rough surfaces; fine-grained, sparkling; resembles beds below, but bedding is thinner, ½–1 ft.; contains two zones of chert concretions; forms bench	15.5
6. Dolomite: like unit 4, but laminae weakly developed; bedding 1–3 ft.; quartz geodes common; one bed at base contains numerous chain-type bryozoans; forms cliff	13.5
5. Dolomite: like unit 4, but laminated throughout; moderately thick-bedded; weathers tan or light gray; black laminae occur etched out on some beds; contains a few ovoid concretions of chert 8×3 in.	11.0
4. Dolomite: gray; fine-grained and sparkling; weathers to light gray very raspy surfaces; some areas locally dark in predominantly light-weathering beds; beds ½–3 ft.; geodes common; forms cliff	9.5
3. Limestone: essentially like unit 1; weathers to light gray rough surfaces; fetid odor; bedding variable, step-like near base, massive and cliff-forming near top. Bed F—little chert except for one bed containing large oval concretions about 20 ft. below top: fossils in lower 7 ft. include: *Archaeocidaris* spines*, crinoid	

	Thickness in Feet
stems*, *Dictyoclostus occidentalis*, *Composita* sp., oval bryozoan colonies; above lower 7 ft., fossils include: *Euomphalus* sp.*, *Bellerophon* sp., small *Murchisonia* type gastropods, *Archaeocidaris* spines, scaphopod, nautiloid, large high-spired gastropods; topmost ledge contains chain-type bryozoan reef, high-spired gastropods*, low-spired gastropods, *Composita* sp., *Camerophoria deloi*	26.5
Bed E—Chert occurs in 1–2 in. bands and in rows of irregularly oval concretions but is less plentiful than in lower beds; beds more massive than those below; fossils include: *Camerophoria deloi**, *Archaeocidaris* spines*, crinoid stems*, *Composita* sp.*, *Squamularia* sp., reef of oval bryozoans, *Avonia* sp., *Dictyoclostus bassi*, *D. occidentalis*, *D. subindicus*	15.0
Bed D—Brecciated in appearance, containing much bedded chert; beds 1–6 in.; at base, 2 ft. bed of small, angular chert fragments with many fossils in middle: fossils include: *Composita* sp.*, *Dictyoclostus bassi**, *Camerophoria deloi**, *Lophophyllum*, bryozoans, small-pored*, fenestellid*, branching	8.5
Bed C—Massive; contains little chert; fossils include: *Dictyoclostus bassi**, *Composita* sp., *Squamularia* sp., *Archaeocidaris* spines, large-pored flat bryozoans	11.0
Bed B—Massive; chert concretions abundant; fossils include: *Composita* sp.*, *Archaeocidaris* spines*, *Squamularia* sp., *Dictyoclostus bassi*, *Chonetes subliratus*, bryozoans, chain type, fenestellid, large-pored type, tiny-pored type (possibly *Chaetetes milleporaceous*)	6.0
Bed A—Massive; no chert; pockets show thin ripple-laminae within the limestone; fossils limited to *Archaeocidaris* spines plentiful in pockets, and to *Euomphalus* sp.	8.0
2. Limestone: buff; fine-grained and arenaceous; weathers to buff, fairly smooth surfaces; locally dark gray; contains considerable chert in concretions and in bands up to 10 in., all weathering dark brown; beds 1–2 ft., slope-forming	18.5
1. Limestone: dark gray; aphanitic to granular; weathers to light gray to dark gray rough surfaces, solution channels common; calcite veins plentiful; beds 2–3 ft.; fossils include: large *Euomphalus* sp.*, *Composita* sp., *Archaeocidaris* spines plentiful in local concentrations	24.5
Total	226.5
Base concealed	

STRUCTURE

Three principal types of movement have governed the history and present exposure of rocks of the northern Canelo Hills. These are, in order of occurrence: (1) an overthrust bringing Permian and younger strata on top of Cretaceous (?) redbeds and Teritary (?) volcanics; (2) high-angle faulting trending generally north-south and east-west, the latter somewhat later than the north-south set; and (3) a gentle anticlinal warping along a northwest-southeast axis.

Since all strata up through the lava sequence are affected by each of the foregoing movements, and since the lavas are interpreted as Tertiary in age, the major movements must have occurred during or after Tertiary time. It is recognized, however, that some extrusive activity may have begun in late Cretaceous time, and that the overthrusting may have been initiated before the close of the Cretaceous.

There is a possibility that some movement is still going on along high-angle fault lines. A road cut 2 miles north of Rail-X Ranch on the road to Sonoita exposes

unconsolidated gravels in which clearly defined movement with a displacement of about 5 feet can be seen. This may, however, be the result of slumping and minor readjustment within the gravels themselves, rather than fault movement.

OVERTHRUST

Appearance of the limestone outcrops in relation to adjacent redbeds in the area is in many places deceptive. It is only when the area is taken as a whole that the overthrust relation of the limestone to redbeds becomes evident.

There are places, notably along the northern margin of the area near Cottonwood Spring, where the strike of limestones and redbeds attains a strong degree of parallelism and dips are not inconsistent with the possibility of a uniform stratigraphic sequence.

However, wider investigation reveals major discordance in attitude between limestones and redbeds in contact. An example occurs in the area about ½ mile north-northwest of Monkey Spring, another in a small redbed outcrop in Dark Canyon just northwest of the summit of Mount Hughes.[18] Further, where erosion has reduced the limestone to a relatively thin sheet, that is, near the thrust surface, bedding is either highly confused or wholly absent.

The long ridge of Permian strata in the northern part of the area suggest the possibility of high-angle faulting. This ridge shows a fairly straight face both on the north and on the south. The interpretation as high-angle faulting is favored by the fact that both north and south faces of the block are in any places scarped to heights ranging from a few feet to a few tens of feet. Some of these scarps show oxidation, minor silicification, and in places even slickensiding. In other localities however, the scarp face shows nothing more than normal limestone. The writer believes that these faces result from a tendency of the limestone blocks to erode back to minor fault surfaces at high angles, or to joints.

Several points in evidence lead to acceptance of the explanation of an o erthrust as the agent which placed the limestone in its present position.

1. Distribution of the limestone remaining uneroded can most logically be explained by overthrusting (Fig. 1). High-angle faults which raised and lowered various parts of the original sheet largely determine the present extent and boundaries of the limestone. However, a highly intricate system of high-angle faults would have to be postulated to explain the pattern of limestone outcrops, were overthrusting to be discounted. This is especially evident in some of the larger re-entrants as that which enters the limestone from the north near a railroad trestle across Sonoita Creek in the northern part of the area.

2. Presence of the classic klippen and fenster indicates overthrust. Klippen wholly or partly detached from the parent masses of limestone may be observed ½ mile north-northwest of Monkey Spring, in Monkey Canyon SW[19], and in the

[18] See Figure 1, areal geology, for location of features mentioned in the text.

[19] Local custom in designating both branches of upper Monkey Canyon as "Monkey Canyon" has been followed, with the subscripts "NE" and "SW" added to differentiate branches.

far southeastern part of the area. Two fensters are found, one in the upper reaches of Monkey Canyon SW, one in Dark Canyon. In addition, certain of the re-entrants suggest that until rather recently the limestone must have closed entirely around them. An example is found about ¼ mile southeast of the fenster in Monkey Canyon SW. The apparent fenster in Dark Canyon is open to question since the lowest redbeds may be Permian in age.

3. The presence above redbeds and volcanics, but below adjacent limestones, of zones of silicification and brecciation suggests movement. These zones are best exposed in Dark Canyon east of Mount Hughes. Here silicified beds, probably originally limestone, are 4–5 feet thick and directly overlie volcanics. Above them is a zone of lime-cemented cobble-size conglomeratic material derived from the Permian limestone. It appears that this is the overthrust zone.

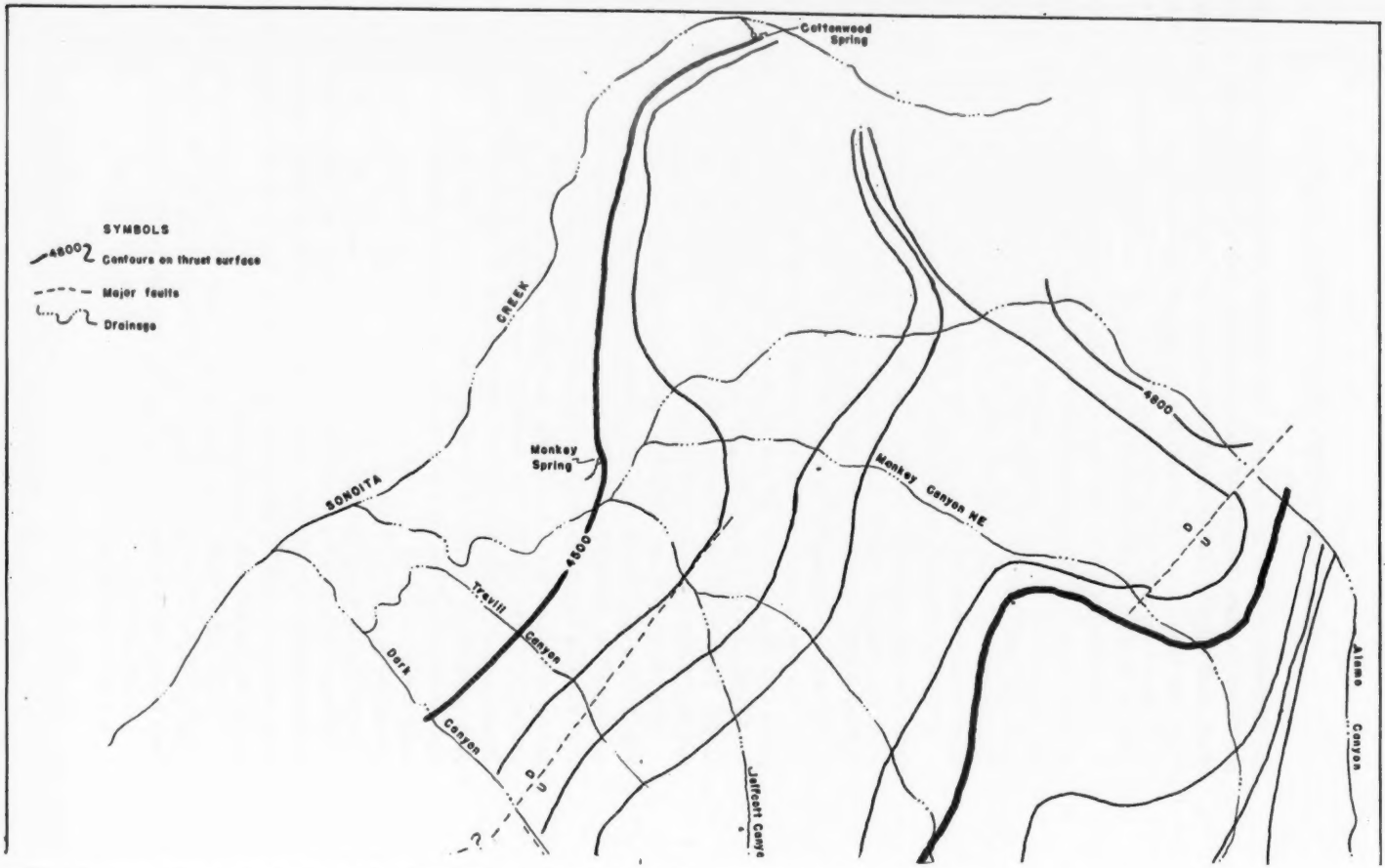
4. The fact that the Permian limestone clearly overlies both redbed and volcanic material suggests overthrust. The limestone is known to be Permain in age, while the redbeds (which contain volcanic fragments) and volcanics must, in light of existing knowledge, be post-Permian since no extrusive rocks are known in southeastern Arizona to be as old as Permian.

5. The exposure, in some of the re-entrant gullies at the north of the area, of faults now dipping about 30° toward the north of northeast suggests overthrust. It is probable that these faults are part of the imbrication pattern of the overthrust. They may have been originally flatter in dip, post-thrust folding being responsible for their present attitude.

The direction from which the overthrust came has not been clearly established, although it has been tentatively interpreted as originating from the northeast and moving toward the southwest. This view is supported by the fact that Permian limestones crop out irregularly throughout a zone at least 2 miles across, peripheral to the area on the east and northeast. Wells drilled in this zone to depths of 150–250 feet are reported to penetrate mainly limestone. Rail-X Ranch drilled a stock well about ½ mile northeast of the northern margin of the area, penetrating 108 feet of "conglomerate" (driller's term; this is assumed to be the Tertiary fanglomerate which flanks the northern Canelo Hills in that direction) before stopping in limestone. Schrader's map[20] shows "Carboniferous" (Permian, as this investigation showed it to be) limestones flanking the Canelo Hills on the northeast side throughout most of their length while none is known to occur from the crest of the hills westward to the Santa Rita Mountains, excepting in the Greaterville area well on the north. The probable imbrication pattern of intra-limestone faulting (see preceding paragraph No. 5) likewise suggests origin of the overthrust from the northeast.

On the other hand, an attempt to reconstruct the surface of the overthrust (Fig. 5), shows the surface dipping in general toward the west and northwest. It may be argued that the dip of that surface has resulted from anticlinal folding of

[20] Frank C. Schrader, *op. cit.*, Pl. I.


SYMBOLS
4800 Contours on thrust surface
Major faults
Drainage
Cottonwood Spring
SONOITA
CREEK
Monkey Spring
4800
Monkey Canyon NE
4800
Trevill Canyon
Dark Canyon
Jaffort Canyon
Alamo Canyon

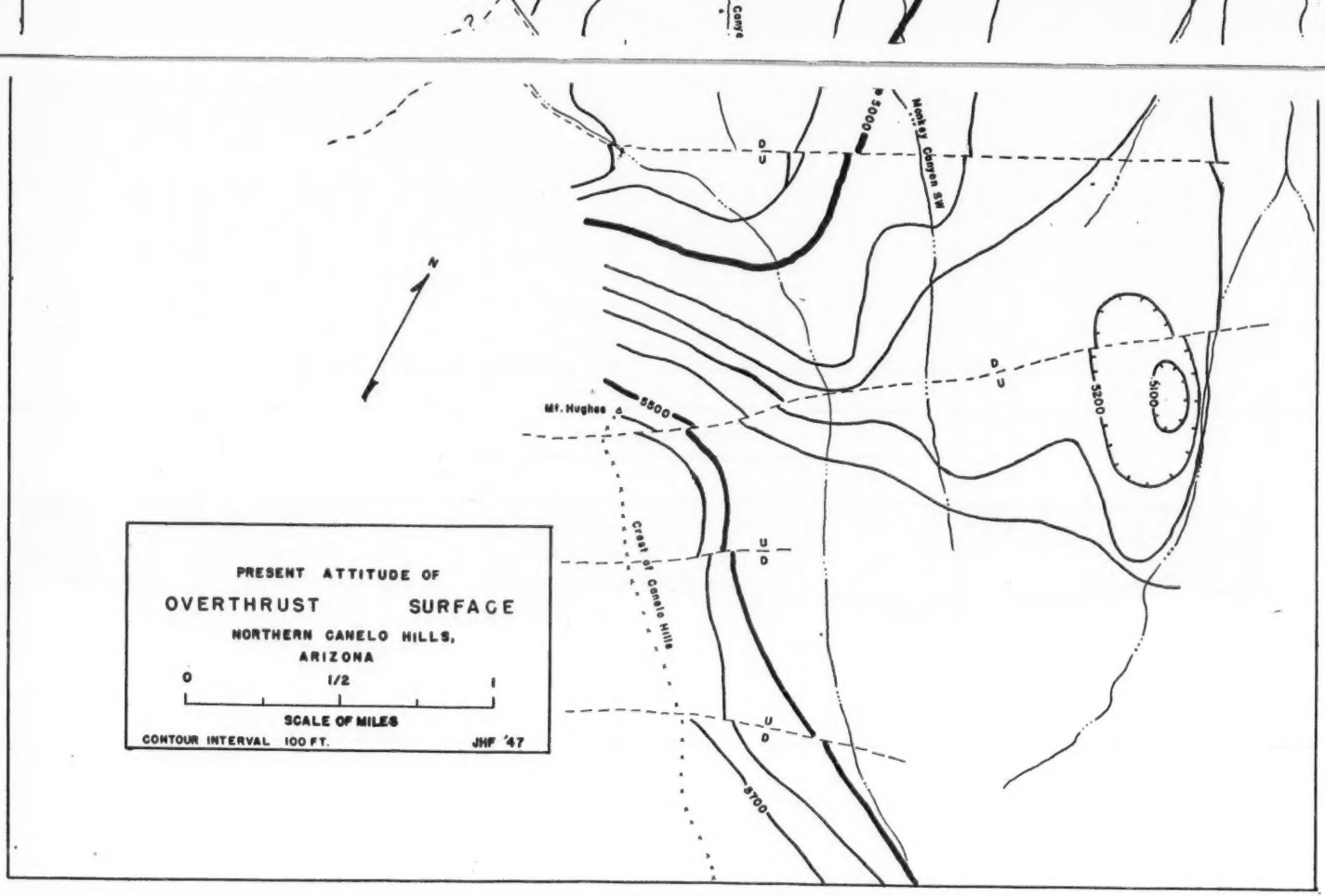

PRESENT ATTITUDE OF
OVERTHRUST SURFACE
NORTHERN CANELO HILLS,
ARIZONA
0 1/2 1
SCALE OF MILES
CONTOUR INTERVAL 100 FT.
JHF '47
N
Mt. Hughes
5800
5000
Hockey Canyon SW
5200
5100
5700
Crest of Canelo Hills
U
D

FIG. 5

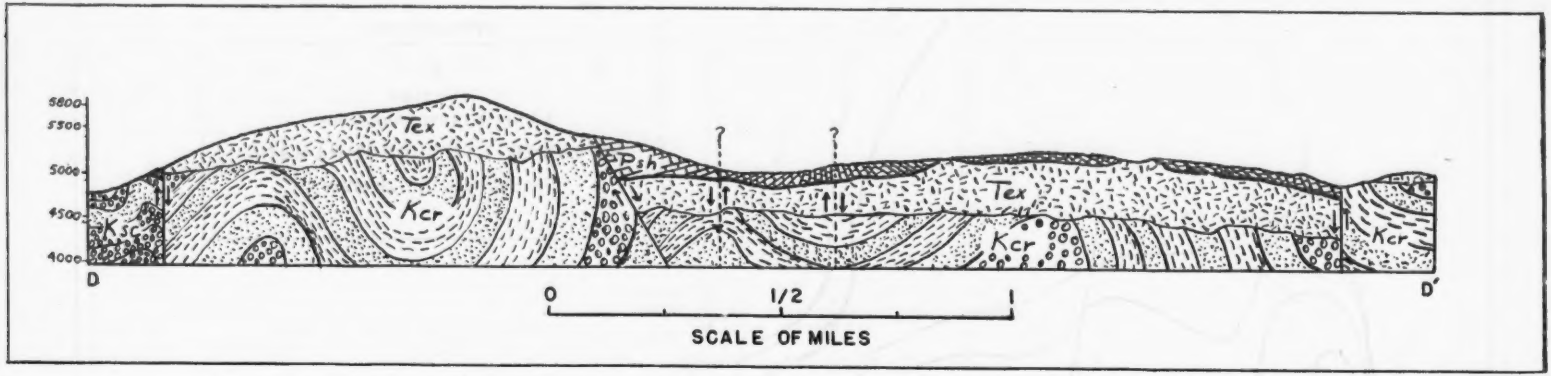


FIG. 6.—Structure section along line *DD'* (Fig. 1). Structure in Cretaceous(?) sediments is schematic.

the area after overthrusting took place. It is hard, however, to visualize the rather gentle folding as reversing the dip of the overthrust surface from north-northeast to its present apparent south-southwest attitude.

While the weight of evidence appears slightly to favor interpretation of the overthrust as coming from the north or northeast, the writer feels that question must remain open pending further regional investigation.

HIGH-ANGLE FAULTING

Much of the present topography appears to be the direct result of two sets of high-angle faults. Although the relationship is not everywhere constant, the set trending generally east-west in some places offsets north-south trending faults. Hence, the east-west set is considered to be somewhat later in age than the north-south group.

These relationships are exemplified in the gorge of Alamo Canyon where the stream transversely cuts the limestone ridge at the northwest corner of the Permian ridge. The guiding factor in causing the gorge is a strong fault striking N. 30° E., and apparently vertical. The canyon thus determined has been offset by a fault striking N. 80° W., which is expressed both by offsetting of the gorge, and by creation of tributary canyons entering Alamo Gorge from east and west at the point of offset.

Another strong, controlling fault occurs on the east slopes of Mount Hughes. Here, apparently, a fault dipping 60° N. 30° E., brings Permian limestone into contact with Tertiary (?) lavas on the flanks of the Canelo Hills. It is assumed that this fault follows in general the line of Dark Canyon along the range. In the next canyon east of Dark Canyon, a fenster of lavas exposed by erosion of the limestones through the overthrust surface is revealed. The floor of Dark Canyon itself just east of the summit of Mount Hughes is composed of redbeds entirely surrounded by Permian limestone. These have been mapped as Cretaceous(?) and appear as a second fenster. However, few volcanics were found within this outcrop either as flows or as fragments, and it remains possible that these are redbeds in the basal part of the Permian section.

This structure is illustrated in the cross-section diagram, DD′ (Fig. 6).

Two interpretations of the major fault here described are possible. It may be either a normal fault with a throw of about 400 feet, or a reverse fault with a vertical displacement of about 2,100 feet. Since there are no apparent objections to the simpler interpretation, the writer prefers to consider it a normal fault.

Some of the faults trending east-west have offset the north-south-trending faults. However, in the main, they seem to have broken across the long northwest-southeast-trending ridges characteristic of the area. Dark Canyon, after it turns northwest around the nose of Mount Hughes, is believed to follow such a fault line. The western foothills of the Canelos show several faults trending generally east-west, along which displacement of the lavas can be seen from one side of a

canyon to the other. Marker beds of sandstone and quartzite interbedded with the volcanics assist in the interpretation.

Another example is furnished by a fault cutting the long ridge of Permian limestone which connects the main northern and southern limestone blocks. Near the middle of this ridge, a vertical fault striking N. 60° E., raised the northern block sufficiently to cause a distinct widening of the remnant of limestone left capping the ridge south of this fault. In this particular area, the bedding north of the fault is almost entirely destroyed. South of the fault, bedding is easily recognized. Since the canyons on either side of this ridge are cut in red shales and sandstones, it is probable that the limestones here are a remnant of the overthrust block so near the sole of the thrust that the bedding has been obliterated. The presence of a fairly abundant and highly typical Snyder Hill fauna south of the fault removes any doubt about the age of the limestones.

No attempt is made to discuss in detail minor high-angle faults which occur in great numbers throughout the area, nor are they by any means all shown on the map. A single illustration indicates their complexity.

In a canyon about $\frac{1}{4}$ mile south of the large travertine exposure at the extreme north-center of the map shown in Figure 1, Cretaceous (?) redbeds form the floor of a re-entrant in the limestone thrust block. Within this canyon, a bed of silicified limestone dipping at a high angle and prominent because of its greater resistence to erosion than adjacent redbeds, strikes almost due north. In a distance of about 200 yards, it is cut through by three high-angle faults and is offset from a few feet to 10 feet on each fault.

Though this is an extreme illustration, it shows the intricate detail of the structural pattern in some parts of the area. Many structures are too small to show on a map of the scale employed in this investigation.

ANTICLINAL STRUCTURE

Figure 1 shows that the general direction of dips on one side of Monkey Canyon SW is northeast, but on the other side of the canyon, the prevailing dip is southwest. This is especially well illustrated in the lavas where marker beds of sandstone and quartzite provide evidence for a close comparison.

All rocks older than the fanglomerate (Tertiary) both on the overthrust block and below the thrust surface appear to have been affected by this gentle arching. It is interpreted, therefore, as being the last of the major structural events in the history of the region for which a time can be fixed with any confidence.

The axis of the fold in general follows the trend of Monkey Canyon SW, striking approximately N. 45° W. In its northwestward (as opposed to its rather abruptly westward course), Monkey Canyon SW may be interpreted as an anticlinal valley, following erosion of the crest of the fold. The structure governing the change of the course of the valley is not clear, but may represent a late phase of the faulting.

The effect of the arching has been principally a steepening of dips northeast and southwest, away from the axis.

SUMMARY OF GEOLOGIC HISTORY

The following summary of events is proposed.

1. Deposition, deformation, and erosion of Permian beds, mainly (as now exposed) the Snyder Hill formation.

2. Deposition, deformation, and erosion of a series of gray and brown sandstones and conglomerates exposed near Corral Canyon (Fig. 1, southwest corner) and characterized by abundance of granite fragments. This series is unique in an area bounded on three sides by faults, on the fourth by valley fill. It is tentatively assigned to the Cretaceous(?).

3. Deposition, deformation, and erosion to a fairly mature topography of a series of redbeds from which granite fragments are completely missing. Also tentatively assigned to the Cretaceous(?), these beds are probably, but by no means certainly, younger than the gray-brown series mentioned in the preceding paragraph. They have been termed the "Canelo redbeds" from their characteristic occurrence in canyons of northern Canelo Hills. Since neither top nor bottom of the section has been established, and since correlation of measured sections remains tentative, no published record has been made of these redbeds to date, nor is priority claimed for the name.

4. Extrusion of rhyolite (Miocene?),[21] andesite (Miocene ?), tuffs and agglomerates (late Miocene?), a younger andesite (late Miocene?); and in Canelo Hills, not mentioned by Schrader, another series of still younger tuffs which form the summit of Mount Hughes and part of the crest of Canelo Hills.

5. Overthrusts extending down into the Permain section, bringing Permian and younger rocks over the Tertiary(?) lavas. It is possible that some of the lavas are older than Schrader has indicated, and that their extrusion and the overthrusting both date back to late Cretaceous time. There is nothing in the area mapped which would serve to clarify this issue, nor have enough regional studies been made to establish a definite time scale.

6. High-angle faulting trending generally north-south.

7. High-angle faulting striking generally east-west.

8. Gentle anticlinal arching along a northwest-southeast axis, steepening dips toward the northeast and southwest away from the axis.

9. Deposition of fanglomerate, probably in Pliocene time, as high hills of volcanics and Permian limestone were eroded. Transition along the flanks of limestone hills from 100 per cent limestone pebbles in the fanglomerate to half limestone, half volcanics and shales, can be traced in these strata as one descends

[21] This and all dates assigned to igneous activity are taken from: Frank C. Schrader, *op. cit.*, pp. 70–75.

from the flanks of the hills into the canyons adjacent. These are the oldest strata not affected by anticlinal folding.

10. Deposition of great valley gravels which now flank the Canelo Hills on the southwest, and the Santa Rita Mountains on the opposite side of Sonoita valley. Interbedded travertine bears a faunule of small gastropods identified[22] as late Pleistocene.

11. Erosion and terracing of valley gravels.

12. Deposition of soil-cover, especially in Sonoita valley where much of it appears to be derived from disintegration of the fanglomerate.

[22] Through the courtesy of Horace G. Richards, Philadelphia Academy of Sciences.

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GENESIS AND EVOLUTION OF LOS ANGELES BASIN, CALIFORNIA[1]

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ABSTRACT

The Los Angeles Basin comprises an area of about 1,200 square miles. It is bounded on the north by mountains uplifted along east-west-trending faults. Most of the regional faulting trends northwest-southeast, resulting in roughly parallel block faults having varied histories of deformation and sedimentation. Paralleling or lying *en échelon* to these faults are topographic prominences varying from mountains along the easterly border to hills and knolls within the plain area. The knolls within this plain reflect anticlinal structures which are now developed as oil fields. Productive areas also occur along the borders of the Basin. Most of the oil deposits are within beds of lower Pliocene and upper Miocene age. Local accumulations also are present in beds of upper Pliocene age, within middle Miocene, and in weathered or fractured schist of the basement complex.

The rocks within the stratigraphic section range in age from Jurassic (?) to Recent. The basement complex consists of various metamorphic and granitic rocks. Remnants of Upper Cretaceous sediments rest on these rocks in the Santa Ana Mountains area and vicinity, and in the Santa Monica Mountains. Eocene sediments also are limited to these two areas. Redbeds ranging in age from middle Miocene to probable Oligocene, inclusive, are rather widespread and were deposited as interfingers with marine sediments. Igneous activity was pronounced in middle Miocene time. Upper Miocene sediments are the most extensive of the marine deposits. Lower Pliocene sediments were deposited in deeper water. Upper Pliocene and lower Pleistocene sediments are rather extensive and were deposited in shallower water and under conditions of marginal oscillations which have resulted in only limited phases of these deposits being present at the edge of the Basin. Active orogenic movement took place at middle Pleistocene time and is continuing to the present. Physiographic features of the Basin are the result of this post-middle Pleistocene activity.

The purpose of this paper is to present a concept of the accumulation, distribution, and distortion of the various rocks within the Los Angeles Basin and to correlate the positions of oil zones within these rocks. Information pertaining to organic content, lithology, stratigraphy, structure, and oil-field data is limited to brief descriptions, charts, sections, and tabulations. More detailed data may be obtained by consulting the publications cited and the references included therein.

Acknowledgment is gratefully made to the management of the Standard Oil Company of California for permission to present these data, to fellow employees who have aided in obtaining field and subsurface data, and especially to W. H. Holman who has cooperated in the examination of material and in the interpretation of data derived therefrom during most of the period in which these investigations were conducted. The views of other geologists, especially the authors of the publications cited, have been freely considered. However, the interpretation of foraminiferal data herein presented is based on observations made by the writer during a period of more than 20 years of laboratory work within the Los Angeles Basin.

Figure 1 shows the principal structural provinces in the vicinity of the Los Angeles Basin. This Basin is bounded on the north by the Santa Monica and San Gabriel Mountains; on the east, in part, by the Santa Ana Mountains; and on

[1] Read before the Association at the Los Angles meeting, March 25, 1947. Manuscript received, September 1, 1947. Published by permission of Standard Oil Company of California.

[2] Geologist, Standard Oil Company of California.

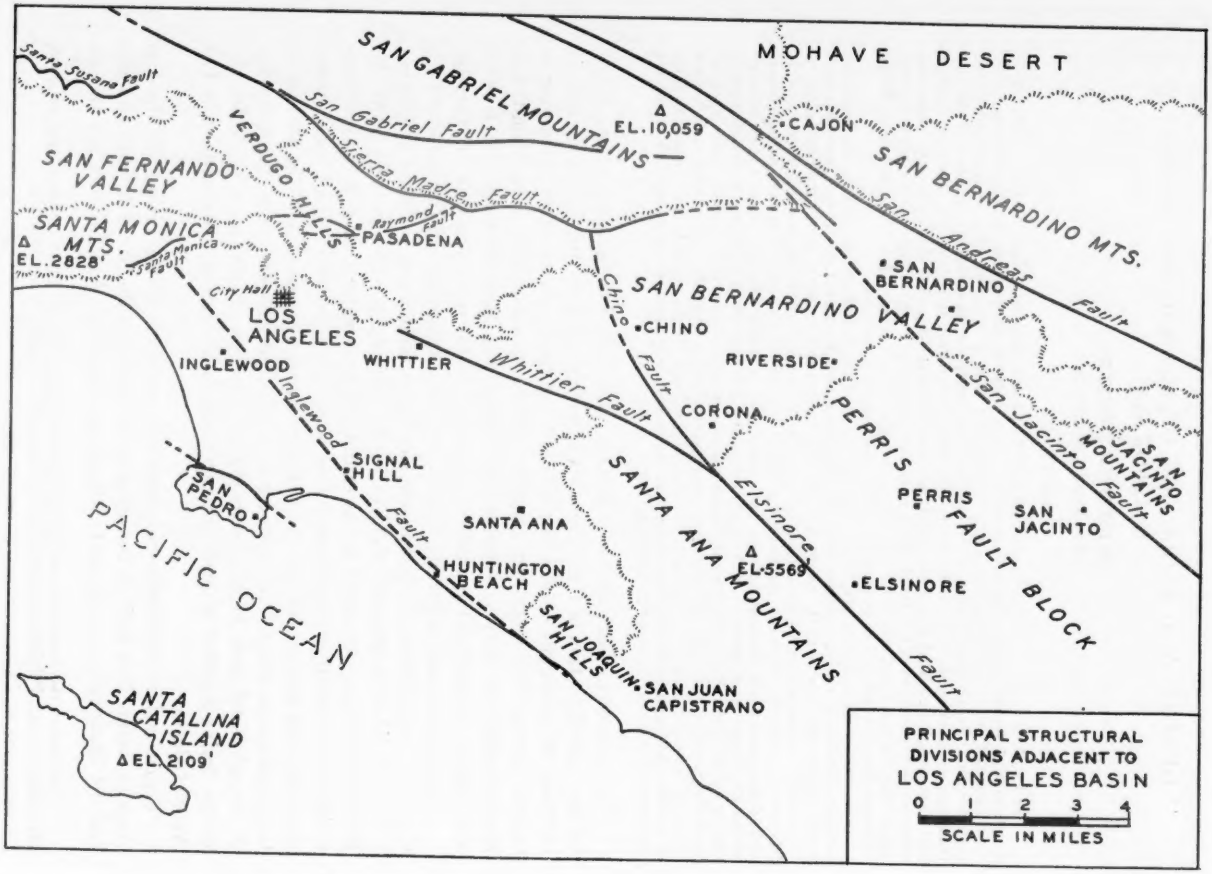
SAN GABRIEL MOUNTAINS
MOHAVE DESERT
Santa Susana Fault
San Gabriel Fault
EL. 10,059
CAJON
SAN FERNANDO VALLEY
VERDUGO HILLS
Sierra Madre Fault
SAN BERNARDINO MTS.
SANTA MONICA MTS.
EL. 2828'
Raymond Fault
PASADENA
Santa Monica Fault
San Andreas Fault
SAN BERNARDINO
City Hall
LOS ANGELES
Chino Fault
SAN BERNARDINO VALLEY
CHINO
INGLEWOOD
WHITTIER
Whittier Fault
RIVERSIDE
Inglewood Fault
CORONA
SAN JACINTO MOUNTAINS
SIGNAL HILL
PERRIS
SAN JACINTO
SAN PEDRO
SANTA ANA
Elsinore Fault
SANTA ANA MOUNTAINS
EL. 5569
PACIFIC OCEAN
HUNTINGTON BEACH
ELSINORE
PERRIS FAULT BLOCK
SAN JOAQUIN HILLS
SAN JUAN CAPISTRANO
SANTA CATALINA ISLAND
EL. 2109'
PRINCIPAL STRUCTURAL DIVISIONS ADJACENT TO LOS ANGELES BASIN
0 1 2 3 4
SCALE IN MILES

FIG. 1

the south and west by the Pacific Ocean and the Palos Verdes Hills. The Los Angeles Basin occupies a roughly rectangular area, with elongate axis extending about 50 miles northwest and southeast, and the shorter axis extending about 25 miles. Most of this area is an alluvium-covered plain comprising truck farms, citrus and walnut groves, residential and industrial areas, and oil fields. It is largely because of these oil accumulations that the extensive industrial development is possible. The genesis and evolution of the Los Angeles Basin may be inferred from a study of the physiographic features; occurrences of oil, gas, and water; areal extent, thickness, and fossil content of sediments; petrologic character of the clastics; and the alteration and contortion of these rocks.

PHYSIOGRAPHY

Physiographic evidence portrays the major fault pattern adjacent to and extending into the Los Angeles Basin. The best known fault in California is the San Andreas, which trends northwest-southeast through Cajon Pass, about 50 miles east of Los Angeles. This fault is readily discernible for more than 500 miles, as evidenced by offset drainage channels and other physiographic features. Additional similarly trending faults are the San Jacinto, the Elsinore and its two northerly branches (the Whittier fault, located along the southwesterly side of the Puente Hills, and the more northerly Chino fault), the Inglewood fault within the Los Angeles Basin, and the Palos Verdes fault located along the northeasterly side of the Palos Verdes Hills. These roughly parallel faults separate fault blocks which have had rather independent histories. An east-west trend of faulting is shown along the south side of the Santa Monica and San Gabriel Mountains. All these faults or zones of faulting dip steeply. Maximum elevations in some of the hills or mountains adjacent to the Los Angeles Basin are: 2,828 feet at Saddle Peak in the Santa Monica Mountains; 10,080 feet at San Antonio Peak (Mount Baldy) in the San Gabriel Mountains; 5,691 feet at Santiago Peak in the Santa Ana Mountains; 1,480 feet at San Pedro Hill in the Palos Verdes Hills; and 2,109 feet at Mount Orizaba on Santa Catalina Island. The greater part of the Los Angeles Basin has an elevation of less than 150 feet, although higher elevations are present in hills near the borders of the Basin and in a linear trend along the Inglewood fault.

GEOLOGY

The oldest rocks present are grouped under the name "Basement complex." Two types of these rocks are involved: the Franciscan series and the Granitic series. The Franciscan series consists of metamporhosed sediments and intrusions of basic igneous rocks, including peridotite, from which the characteristic constituent, serpentine, is derived. This type of rock is exposed in the Palos Verdes Hills and on Santa Catalina Island. These two localities are considered to be continental remnants referred to as the Catalina landmass, most of which

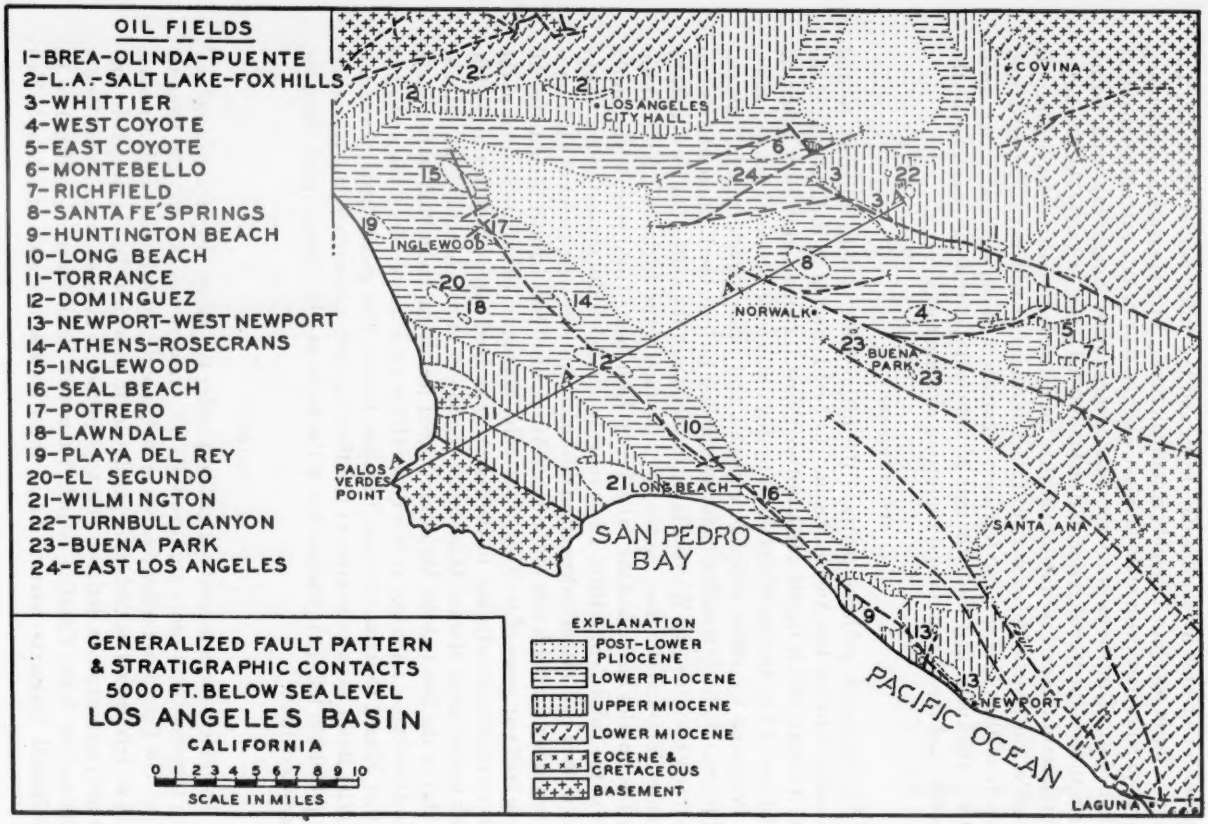
OIL FIELDS
1-BREA-OLINDA-PUENTE
2-L.A.-SALT LAKE-FOX HILLS
3-WHITTIER
4-WEST COYOTE
5-EAST COYOTE
6-MONTEBELLO
7-RICHFIELD
8-SANTA FE SPRINGS
9-HUNTINGTON BEACH
10-LONG BEACH
11-TORRANCE
12-DOMINGUEZ
13-NEWPORT-WEST NEWPORT
14-ATHENS-ROSECRANS
15-INGLEWOOD
16-SEAL BEACH
17-POTRERO
18-LAWNDALE
19-PLAYA DEL REY
20-EL SEGUNDO
21-WILMINGTON
22-TURNBULL CANYON
23-BUENA PARK
24-EAST LOS ANGELES
LOS ANGELES CITY HALL
COVINA
INGLEWOOD
NORWALK
BUENA PARK
PALOS VERDES POINT
LONG BEACH
SAN PEDRO BAY
SANTA ANA
NEWPORT
PACIFIC OCEAN
LAGUNA
GENERALIZED FAULT PATTERN
& STRATIGRAPHIC CONTACTS
5000 FT. BELOW SEA LEVEL
LOS ANGELES BASIN
CALIFORNIA
0 1 2 3 4 5 6 7 8 9 10
SCALE IN MILES
EXPLANATION
POST-LOWER PLIOCENE
LOWER PLIOCENE
UPPER MIOCENE
LOWER MIOCENE
EOCENE & CRETACEOUS
BASEMENT

FIG. 2

occupied the present continental shelf. The Franciscan series is referred to as Jurassic (?) in age.

The Granitic series consists of quartz diorite and other granitoid intrusives and metamorphosed sediments. In the vicinity of the Los Angeles Basin, this type of rock is exposed on the islands extending westward from the Santa Monica Mountains, and on the mainland in the Santa Monica, San Gabriel, and Santa Ana Mountains, and comprises most of the rocks in the easterly mountainous areas. These rocks are considered to be Jurassic and Triassic in age, although some of them may be Paleozoic or older. Some of the metamorphosed sediments contain Triassic fossils. In the Santa Ana Mountains, granitoid intrusives cut Triassic metamorphics and are thought to contribute pebbles to overlying Upper Cretaceous conglomerates, thus dating these intrusives as probably Jurassic in age.

The activities of field geologists in the Los Angeles Basin are greatly curtailed because of the limited areal extent of outcrops. Office geologists are somewhat less concerned with these limitations, because through the use of available data from field geology, information obtained from wells, geophysical results, and ready application of vivid imagination (a requisite for all geologists), subsurface conditions may be visualized. Figure 2 portrays the generalized fault pattern and stratigraphic contacts which may be expected if visualized after the rocks have been scooped out along the coast and across the Los Angeles Basin to a depth of 5,000 feet below sea-level.

Figure 3 presents a simplified stratigraphic section as interpreted for this area. These results are based chiefly on the organic and petrologic examination in the Los Angeles laboratory of the Standard Oil Company of California of thousands of samples obtained from numerous wells, more than 26 of which were drilled below 10,000 feet and 10 of which were drilled below 12,000 feet. The most comprehensive data of this nature pertaining to the Los Angeles Basin which have been published were presented by S. G. Wissler (42).[3]

The stratigraphic units are grouped in the following manner on the accompanying map and chart.

Basement complex.—The Basement complex represented at 5,000 feet below sea-level by Franciscan schist in the Palos Verdes Hills and near the coastal area of the Torrance structure. It is also present in deep wells in the Inglewood, Dominguez, and Long Beach fields, and in the intervening area to the coast. Granitic rocks are represented at 5,000 feet below sea-level in the Santa Monica Mountains and in the San Jose Hills. These rocks have been estimated to be as much as 16,000 feet thick in the Santa Monica Mountains (20).

Cretaceous and Eocene.—These sediments crop out in the Santa Monica and Santa Ana Mountains (26). The Cretaceous is limited to the upper division and rests directly on basement rocks. It is represented at both localities by lower Chico conglomerate, locally referred to as the Trabuco formation in the Santa

[3] Number refers to the sequence of references listed in the bibliography.

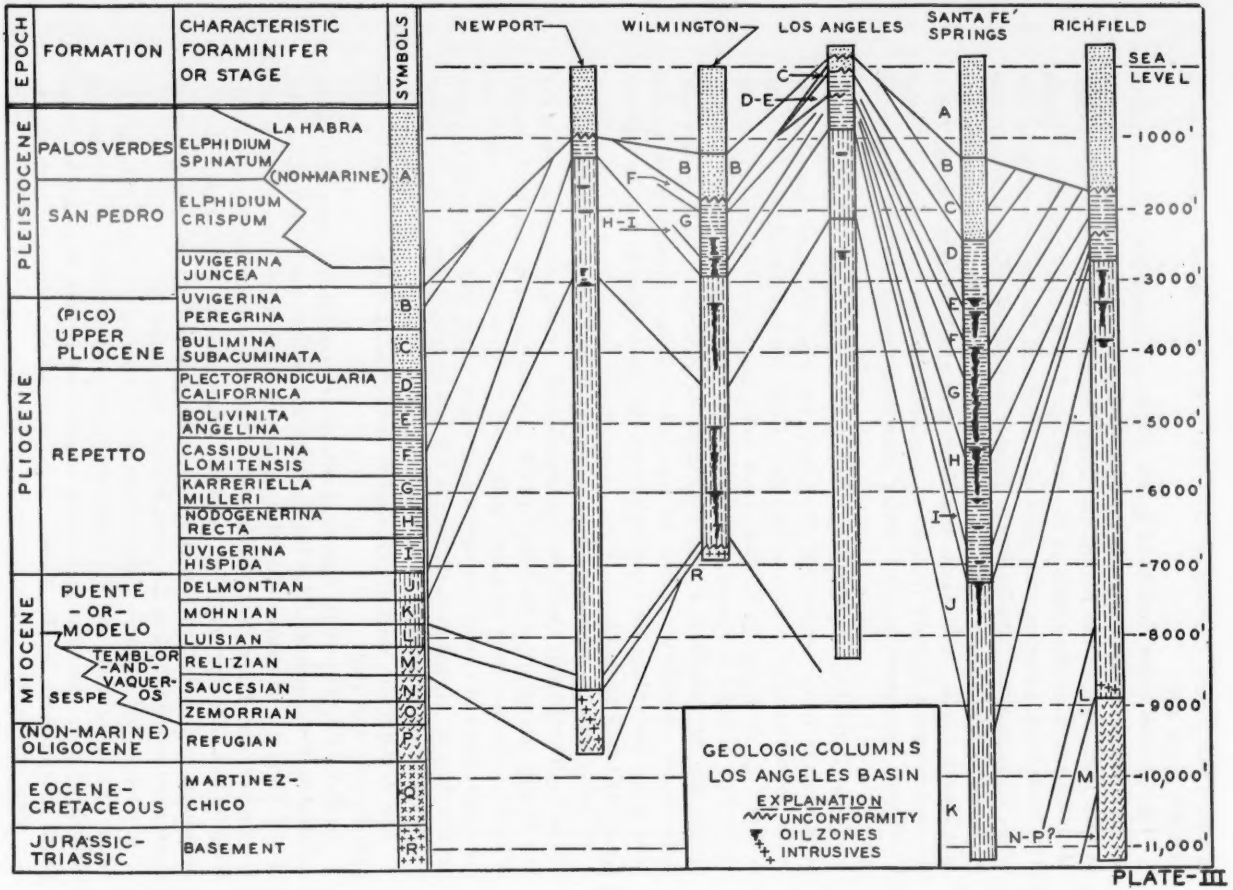
EPOCH
FORMATION
CHARACTERISTIC FORAMINIFER OR STAGE
SYMBOLS
PLEISTOCENE
PALOS VERDES
LA HABRA
ELPHIDIUM SPINATUM
(NON-MARINE)
SAN PEDRO
ELPHIDIUM CRISPUM
UVIGERINA JUNCEA
PLIOCENE
(PICO) UPPER PLIOCENE
UVIGERINA PEREGRINA
BULIMINA SUBACUMINATA
REPETTO
PLECTOFRONDICULARIA CALIFORNICA
BOLIVINITA ANGELINA
CASSIDULINA LOMITENSIS
KARRERIELLA MILLERI
NODOGENERINA RECTA
UVIGERINA HISPIDA
MIOCENE
PUENTE -OR- MODELO
DELMONTIAN
MOHNIAN
LUISIAN
TEMBLOR -AND- VAQUEROS
RELIZIAN
SESPE
SAUCESIAN
ZEMORRIAN
(NON-MARINE) OLIGOCENE
REFUGIAN
EOCENE-CRETACEOUS
MARTINEZ-CHICO
JURASSIC-TRIASSIC
BASEMENT
NEWPORT
WILMINGTON
LOS ANGELES
SANTA FE SPRINGS
RICHFIELD
SEA LEVEL
1000'
2000'
3000'
4000'
5000'
6000'
7000'
8000'
9000'
10,000'
11,000'
N-P?
GEOLOGIC COLUMNS
LOS ANGELES BASIN
EXPLANATION
UNCONFORMITY
OIL ZONES
INTRUSIVES
PLATE-III

FIG. 3

Ana Mountains, and by upper Chico conglomerate, arkosic sandstone, and minor amounts of shale and limestone. Their age is based on fossil evidence. A thickness of more than 8,000 feet is indicated. The Upper Cretaceous sea probably was warm and rather shallow and may have extended over a large part of the Los Angeles Basin, although only remnants of these deposits remain. The sources of these sediments were chiefly from granitic landmasses on the north and east. These deposits are present east of Santa Ana at the datum 5,000 feet below sea-level.

Eocene in the Santa Monica Mountains is confined to the lower member, Martinez equivalent, which was deposited under conditions similar to those that existed during Chico time. The fossil content is distinctive. In the Santa Ana Mountains, the Martinez is separated by unconformities from the Chico and from the overlying upper Eocene, Tejon. A total thickness of as much as 4,000 feet is reported to be present. Eocene sediments have been reached in some wells drilled along the Anaheim nose, extending northwesterly from the town of Anaheim.

Oligocene and lower Miocene.—The presence of Oligocene is uncertain, and if present is represented by non-marine sediments. These non-marine rocks are considered to vary in age up into the Luisian stage of the Miocene, and, therefore, occupy the stratigraphic equivalent assigned, in most part, to the Sespe formation. They consist of reddish conglomerate and gray sandstone locally interbedded with reddish and greenish sands and clays, and, within the lower Miocene equivalent, grade into marine sediments containing Vaqueros and Topanga (Relizian stage) fossils. The marine facies is best developed in the Santa Monica and Santa Ana Mountains, and in the San Joaquin Hills. The marine Vaqueros is confined largely to the southern part of the Basin and is limited to a thickness of a few hundred feet of chiefly conglomerate, gray sand, and sandy shale. Marine Topanga beds consist of similar sediments associated with tuffs, breccias, and basaltic intrusives, and, in addition to the foregoing localities, occur as the equivalent of the lower part of the Altamira shale member in the Palos Verdes Hills. Redbeds of this series rest directly on granitic basement rocks in the vicinity of San Jose Hills, and underlies Puente sediments in some wells within the eastern part of the Basin. As much as 8,500 feet of rocks accrued in this series. The period was initiated by extensive withdrawal of the sea from the Los Angeles Basin and was terminated by sinking of the landmass, which permitted the greatest transgression made by the sea in this area. The resulting unconformity marks the most pronounced pre-Pliocene deformation.

Upper Miocene.—The upper Miocene includes the Luisian, Mohnian, and Delmontian stages (24), or the Puente and, in part, the Topanga formations, along the eastern border of the Los Angeles Basin; the series referred to the Monterey shale, excepting the lower part of the Altamira shale member (Relizian) in the Palos Verdes Hills; and the Modelo formation in the Santa Monica Mountains. Well preserved Foraminifera of the Luisian stage associated with diatomite, crop out in the "Topanga" in the vicinity of the San Jose Hills, showing that

these rocks are younger than the Topanga (Relizian) of the type locality in the Santa Monica Mountains area. Other occurrences of Luisian Foraminifera are: in outcrops near Newport; in the middle Altamira shale member within the Palos Verdes Hills; in well samples from just above the schist conglomerate in the Wilmington field; near the eastern extremity of the Torrance field; in wells within the Newport, Huntington Beach, and Inglewood fields; and in some wells near the eastern border of the Basin. The coastal area north of the Palos Verdes Hills was apparently a landmass during this stage, because sediments containing middle Mohnian Foraminifera rest on schist or schist conglomerate. This deduction is supported by the occurrence of mollusks of upper Miocene age in the conglomerate (4). Rocks of the Mohnian and Delmontian stages comprise the Puente formation, which forms extensive outcrops within the Basin.

Upper Miocene rocks are present at 5,000 feet below sea-level in a band along the northern edge of the Basin, in the Huntington Beach-Newport area, in the eastern Montebello field, and along the Whittier fault. This series contains sandstones, local conglomerates, granitic intrusives, and altered ash, and is characterized by brown laminated siliceous and calcareous shales associated with diatomaceous and radiolarian deposits. Another rock type of importance because of its bituminous character is a black shale containing phosphatic nodules derived, at least in part, from fish remains. This shale body has a thickness ranging up to 150 feet, is best developed in the vicinity of Playa del Rey, and lies within the Mohnian stage. It is probably a rather deep-water facies, and is not restricted to a definite stratigraphic position. The upper Miocene sediments were apparently deposited in shallow to fairly deep, cool water and are estimated to occur in a maximum thickness of approximately 10,000 feet. Both granitic and Franciscan landmasses served as source rocks.

Lower Pliocene.—Lower Pliocene sediments are limited to the Repetto formation within the Los Angeles Basin. Their type locality is within the Repetto Hills, along the northern border of the Basin. The rocks are commonly sand and massive brownish gray shale and sandy shale, and attain a thickness of as mcuh as 4,000 feet. Sediments containing typical Repetto fauna are exposed along the northern border of the Basin; along the western and northern extremities of the San Jose and Puente Hills; near Newport Bay; in patches along the northern and western edges of the Palos Verdes Hills; and in an embayment near San Juan Capistrano (just off the southern edge of the map), where these rocks unconformably overlie radiolarian mud-rock of the middle Mohnian stage. At 5,000 feet below sea-level, the Repetto rocks form a band which practically circles the Basin and probably forms a narrower encirclement of a minor basin west of Covina. Typical Repetto foraminiferal assemblages indicate deep, cool-water deposition. The sea was less widespread and deeper than in upper Miocene time, but the change is considered to be rather gradual, because the contact with the Miocene is normal excepting along the borders of the Basin. Marginal foraminiferal assemblages within the Repetto tend to assume similarities to younger Pliocene faunas,

indicating deposition at shallower depths. These sediments were derived essentially from northerly source rocks. The younger Repetto beds are generally more widespread than the older beds. Local interruptions in deposition of these sediments have taken place near the borders of the Basin.

Post-lower Pliocene.—The sea continued its transgression although interruptions in deposition in the marginal areas became more marked and frequent. As a result, the upper Pliocene is only partly represented in outcrop material. One of the best exposed sections is in Potrero Canyon, near Santa Monica, where a little more than 600 feet of upper Pliocene sediments is present, whereas these beds attain a thickness of several thousand feet in the central part of the Basin. Other limited outcrops of upper Pliocene sediments extend eastward to the edge of the San Jose Hills and occur locally in the Newport area. The name Pico formation has commonly been applied to these beds, but the type locality for this formation includes both the equivalent of these sediments and the equivalent of the Repetto formation. The limited number of outcrops from which to choose a type section undoubtedly has deterred the selection of a less confusing local name. The beds in this Basin conssit essentially of sands, local conglomerates, and rather massive olive-gray siltstone to sandy shale. These sediments apparently were deposited in a rather shallow sea and were derived chiefly from northern source rocks.

The correlation of sediments within Palos Verdes Hills presented in United States Geological Survey *Professional Paper 207* (49) shows the Lomita marl, the San Pedro sand, and the Timms Point silt to be lower Pleistocene in age and to be contemporaneously deposited near the base of the section. Since the Lomita marl, contains a foraminiferal assemblage belonging to the *Uvigerina peregrina* zone, and since this zone is also present in Pliocene rocks, the Pleistocene-Pliocene contact is considered to lie within the upper part of this zone. The marine San Pedro sand has the greatest thickness of these members and is unconformably overlain by marine Palos Verdes sand of upper Pleistocene age.

Marked interruptions in sedimentation and distortion of beds occurred during Pleistocene time. These sediments were deposited in water which ranged in depth from shallow to about 100 fathoms, being typically cold in the lower Pleistocene with some warmer-water fluctuations in the lower part, and being typically warm in the upper Pleistocene. These temperature facies have been variously correlated with glacial and interglacial periods. Pleistocene rocks were derived from both Franciscan and granitic sources. These deposits have a thickness up to about 1,800 feet in this Basin, and, in addition to the Palos Verdes Hills, crop out near Playa del Rey and Santa Monica and at Inglewood, Long Beach, and West Coyote fields. The marine Pleistocene grades into non-marine reddish sands and conglomerates in the eastern part of the Basin. These non-marine facies have been referred to the La Habra formation (10), named for the town near which they are typically developed. Brackish-water Pleistocene organisms have been obtained from wells near the center of the Basin.

The post-lower Pliocene sediments present at 5,000 feet below sea-level are confined to upper Pliocene beds in the central part of the main Basin and in the minor basin west of Covina. Figure 4 presents a structural section across the Basin from Palos Verdes Point through the Whittier oil field.

IGNEOUS ACTIVITY

Volcanic activity was apparently initiated during lower Miocene (Saucesian) time, increased during the Relizian stage, and culminated during the Luisian stage. The earlier igneous rocks commonly consist of andesitic sills and dykes, followed by basaltic material and breccias. When igneous activity was most pronounced, volcanic outbursts contributed appreciable thicknesses of tuffs, agglom-

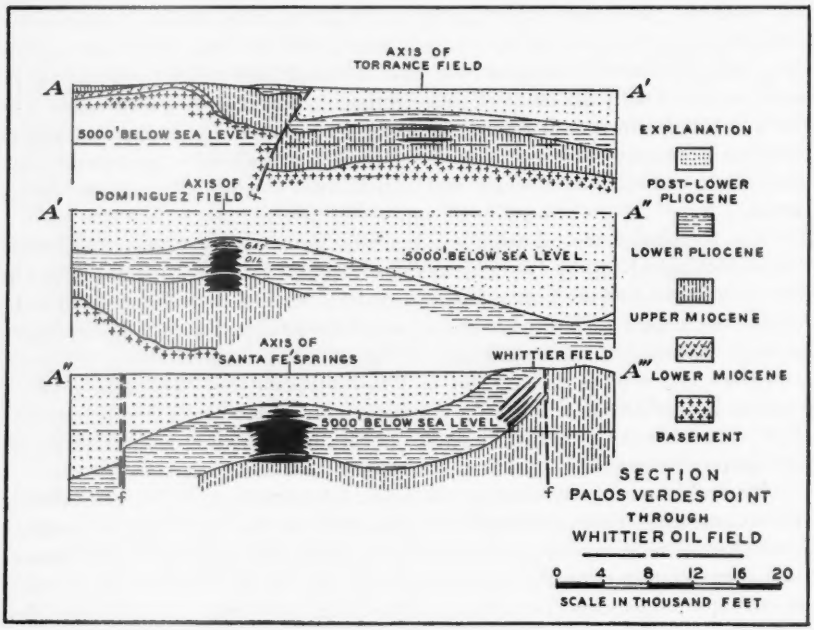

FIG. 4

erates, and breccias in the vicinity of the San Jose Hills, Santa Monica Mountains, and San Joaquin Hills. Igneous activity then subsided, but thin seams of tuff, volcanic glass, and bentonitic material derived from altered ash are commonly present even in upper Miocene and here and there in lower Pliocene sediments. For example, a bentonitic bed has been found to serve as a useful means of correlation shortly below the "B" zone sand in the upper Miocene (Delmontian) of the

West Newport field, and another bentonitic bed has been used as a marker within the lower Pliocene in the Inglewood field.

DIASTROPHISM

The present continental shelf bordering the Los Angeles Basin has had a varied history of emergence and submergence (25). It was probably not sufficiently prominent as a landmass to contribute much of the Cretaceous and Eocene sediments. Its most prominent emergence is considered to have occurred during the Relizian stage of the lower Miocene, when this area served as a source for deposits in the southeastern part of the Basin. These sediments, in their northerly and easterly extension, mingled with those derived from landmasses in these directions, which during this time were well degraded. Rejuvenation of the northern and eastern landmasses took place during the upper Miocene and was accompanied by appreciable degradation or partial submergence of the Catalina (continental shelf) landmass. Similar relative conditions prevailed until the end of the Pliocene epoch. In mid-Pleistocene time, a period of deformation which began earlier became intense and has continued to the present, as may be attested by periodic earthquakes, during one of which, on October 21, 1941 (56), the casing in 15 flowing wells in the Dominguez field was crushed.

Very few of the present physiographic features are believed to have existed prior to upper Pleistocene time. The remains of dwarfed elephants in Pleistocene rocks on some of the islands in the Santa Barbara Channel suggest that these islands were connected to the mainland during this time and formed the western extension of the Santa Monica Mountains. Fossil evidence indicates that this landbridge was destroyed by movement of fault blocks in comparatively late geologic time. Marine terraces offer additional evidence of comparatively recent fluctuations of landmasses in reference to sea-level. Five distinct marine terraces were noted along the southwesterly slope of the San Joaquin Hills, between elevations of 75 and 975 feet above sea-level,[4] and 13 marine terraces were recorded in the Palos Verdes Hills, at elevations of 100 to 1,300 feet (49).

Major faults within the Los Angeles Basin indicate histories similar to the faults which border fault blocks adjacent to this Basin, in that they are steep, generally trend northwest-southeast, and commonly indicate lateral movement of the western block in a northerly direction in reference to the eastern block. The amount of this lateral displacement varies, but it amounts to as much as several hundred feet along the Inglewood fault. The compressive forces were, in part, relieved by this movement along the faults and were, in part, taken up by folding of strata. Some of this folding took place during deposition, for sediments are commonly thicker along the flanks of structures than along their crests. The release of compressive forces in anticlinal folds was followed, in several cases, by tensional adjustments resulting in normal faulting. For example, the axes of the

[4] Geologic report by G. B. Moody, Standard Oil Company of California.

TABLE I

PRODUCTION STATISTICS TO JANUARY 1, 1947 - LOS ANGELES BASIN FIELDS

		Discovery				Maximum Production			Present Production		Range of Production			Accumulated Production (Barrels)	Approx. Proved Acreage
*No.	Oil Field	Company	Well	Date	Depth	Date	Barrels Per Day	No. of Wells	Barrels per Day	No. of Wells	Feet	†Stratigraphic Zones	Gravity		
1	Brea-Olinda-Puente	Puente Oil Co.		Jan. 1890	150	Dec. 1926	26,776	457	11,263	359	1,500- 5,800	F - K	14-28°	188,962,959	1,550
2	Los Angeles-Salt Lake-Fox Hills	E. L. Doheny, et al.		(L.A.) 1892	155	Jan. 1909	17,530	643	161	82	150- 4,200	J - K	13-16°	20,045,555	900
		Salt Lake Oil Co.		(S.L.) 1902	900				231	10		K		46,919,070	
3	Whittier	Central Oil Co.	#1	1897	948	June 1917	5,500	156	1,016	161	700- 4,200	G - K	14-24°	20,296,013	485
4	West Coyote	Murphy Oil Co.	Murphy-Coyote #3	Apr. 26, 1909	3,490	June 1918	31,600	63	15,037	204	2,600- 6,335	D - H	22-33°	148,919,127	1,000
5	East Coyote	Amalgamated Oil Co.		Mar. 25, 1911	3,353	Apr. 1917	10,385	79	4,563	162	2,540- 7,079	F - K	14-25°	53,245,236	2,200
6	Montebello	Standard Oil Co.	Baldwin #1	Feb. 27, 1917	2,395	June 1919	38,051	78	7,872	346	1,500- 8,850	F - K	16-42°	145,821,818	1,460
7	Richfield	Union Oil Co.	Chapman #1	Mar. 11, 1919	3,060	Oct. 1921	27,762	136	6,997	329	2,100- 4,700	J - K	12-28°	108,521,528	2,000
8	Santa Fe Springs	Union Oil Co.	Meyer #3	Oct. 3, 1919	4,595	Aug. 1923	328,367	196	16,539	545	3,500- 7,700	D - J	27-34°	511,455,992	1,450
9	Huntington Beach	Standard Oil Co.	Huntington #1A	Aug. 3, 1920	2,381	July 1923	116,000	212	47,356	890	1,953- 7,604	D - K	13-29°	378,028,032	2,050
10	Long Beach	Shell Co.	Alamitos #1	June 20, 1921	3,114	Oct. 1923	246,309	272	23,977	1,105	2,300-10,640	C - K	16-32°	717,867,030	1,400
11	Torrance	C.C.M.O.	Del Amo #1	June 6, 1922	3,500	May 1924	57,419	378	8,392	730	2,780- 5,400	H - K	13-29°	119,599,055	4,005
12	Dominguez	Union Oil Co.	Callender #1A	Sept. 1, 1923	4,068	Jan. 1925	57,017	45	14,896	322	3,900- 8,100	D - J	22-33°	167,759,682	1,000
13	Newport-West Newport	Newport Oil & Ref. Co.	Well #2	Aug. 24, 1923	900	Dec. 1946	7,611	123	7,611	123	1,345- 5,973	J - K	12-23°	2,412,156	700
14	Athens-Rosecrans	Union Oil Co.	Howard Park #1	May 3, 1924	4,971	Oct. 1925	25,253	93	4,866	183	4,190- 9,618	D - J	29-42°	59,237,701	715
15	Inglewood	Standard Oil Co.	L.A. Invest. #1-1	Sept.28, 1924	2,134	Aug. 1925	104,159	138	12,136	308	1,225- 8,934	B - L	15-44°	156,145,736	875
16	Seal Beach	Marland Oil Co.	Bixby #2	Aug. 6, 1926	4,427	June 1927	65,830	97	10,634	168	4,400-10,194	F - K	24-32°	105,655,526	1,000
17	Potrero	Tide Water Assoc.Oil Co.	Cypress #2	Apr. 12, 1928	4,619	June 1930	3,982	11	670	26	2,941-10,418	B - J	28-51°	6,044,261	250
18	Lawndale	San Clemente Oil Co.	Peck #1	July 26, 1928	5,818	June 1929	1,730	6	19	4	5,900- 6,300	J	26-29°	1,115,302	25
19	Playa del Rey	Ohio Oil Co.	Recreation Gun Club #1	Dec. 19, 1929	6,199	Nov. 1930	40,415	109	2,245	120	3,500- 6,500	F - R	15-23°	52,353,147	730
20	El Segundo	Republic Pet. Co.	Security #1	Aug. 20, 1935	7,405	Oct. 1937	21,835	33	553	26	7,100- 7,600	K - R	14-27°	11,738,079	950
21	Wilmington	General Pet. Corp'n	Terminal #1	Dec. 6, 1936	3,625	Mar. 1938	127,079	418	117,854	1,615	2,446- 6,300	H - R	12-34°	320,934,970	4,240
22	Turnbull Canyon	Continental Oil Co.	Turnbull Comm. #1	Oct. 18, 1941	3,447	Jan. 1943	442	4	111	5	3,630- 4,070	J	27°	443,185	30
23	Buena Park	The Texas Co.	Spencer #1	Mar. 6, 1942	8,980	Sept. 1942	329	3	62	2	9,325-11,422	F - G	23-28°	187,598	20
24	East Los Angeles	Richfield Oil Corp'n	U. P. Unit #1	Feb. 2, 1946	8,590	Sept. 1946	769	4	659	4	7,952- 9,238	J	35-37°	178,836	240

* Sequence in discovery. See Fig. 2 for locations.
† See Fig. 3.

Inglewood and Dominguez fields are cut by grabens, and complex faulting is present in the Wilmington, Huntington Beach, and West Newport fields. Vertical displacement along the faults is commonly appreciably more pronounced with depth than at the surface. Topographic evidence indicates a vertical displacement of the Inglewood fault in a marine Palos Verdes terrace at the surface in the Huntington Beach field to amount to about 40 feet, whereas data from wells in the southeastern part of the field show a vertical displacement in excess of 1,000 feet.

OIL OCCURRENCES

Surface evidence has led to the discovery of most of the oil fields within the Los Angeles Basin. The Brea-Olinda field, discovered in January, 1890, was the first of these fields to produce oil in commercial quantities. As the name implies, this discovery was guided by the presence of brea deposits. Other fields near the northern and eastern margins of the Basin also lie in the vicinity of oil seepages. For example, the Salt Lake field, discovered in 1902, is located near the Tar Pits from which extensive collections of Pleistocene verbetrates have been obtained (35) and where tar and bubbles of gas still exude. Separate topographic prominences within the Los Angeles Basin have been found to be anticlinal structures and are now developed into oil fields. The axes of the productive areas generally trend northwest-southeast and lie *en échelon* in rows having a general northwest-southeast alignment. Twenty-four major oil fields have been discovered within the Los Angeles Basin, all of which are known to be associated with faulting. Complexities of faulting have resulted in some of the fields being divided into different areas of production. For example, the Huntington Beach field is divided, by faulting, into the Offshore, Townlot, Barley Tract, A-37, Main Street, Surf, Main Field, and Five Point areas. Figure 3 shows composite columns determined from wells located in the north, south, east, west, and central parts of the Los Angeles Basin. Commercial oil zones range in stratigraphic position from the Basement complex of probable Jurassic age to the *Uvigerina peregrina* zone of the upper Pliocene. Oil occurs in some local areas in the Basement complex within cavities resulting from weathering or from fault fractures. The oldest productive sediments are within the Luisian stage of the Inglewood and Wilmington fields. Several fields contain productive zones in one or more of the stratigraphic divisions designated as Mohnian or Delmontian stages of the upper Miocene, or as lower Pliocene. The only commercial oil produced above the lower Pliocene is that obtained from the uppermost zones in the Inglewood, Potrero, and Long Beach oil fields. The sequence of discovery of the oil fields in this Basin is indicated by the number opposite the field as shown in Figure 2. The Long Beach field is outstanding in that a continuous interval of as much as 3,000 feet has been produced near the crest of the structure and, in 1946, the Shell Oil Company's Alamitos well No. 48A produced oil from what was then the deepest interval open to production in the world, namely, from 12,853 to 14,947 feet. The total cumu-

lative oil production from the Los Angeles Basin to January 1, 1947, amounts to 3,344,620,568 barrels, or 45.79 per cent of the total cumulative production of 7,304,805,284 barrels for the state of California. This total cumulative oil production from the Los Angeles Basin contains about 633,000 barrels from scattered localities which are not included within the 24 fields listed in Table I (53).

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VOL. 32, NO. 1 (JANUARY, 1948), PP. 126-128, 1 FIG.

GEOLOGICAL NOTES

SO-CALLED MAQUOKETA OF BARBER COUNTY, KANSAS[1]

WALTER A. VER WIEBE[2]
Wichita, Kansas

One of the important producing zones in Barber County, Kansas, is an argillaceous rock lying above the typical coarsely crystalline limestone called Viola. This rock is commonly termed the Moquoketa, and it is so carried in numerous scout reports. Geologists in Wichita do not all agree that this layer should be called Maquoketa. Many believe as the writer does, that this particular lithologic unit forms a part of the Viola sequence.

In order to clarify the problem the writer studied cuttings from all wildcat tests in Barber, Harper, Comanche, Pratt, Edwards, Kiowa, and Pawnee counties, and many selected wells in Reno and Stafford counties. This study reveals that the Viola of this part of Kansas can be divided into six zones, as shown in Figure 1. From this generalized diagram it will be noted that each of the six zones in the Viola has certain characteristics which can be traced from well to well.

In Barber County all zones are present, excepting the top one or zone I. This is not to say that all zones are present over the whole extent of the county. In fact, erosion has removed the upper zones in varying amounts and in a certain restricted area only the lowest two zones are left.

The lowest zone (zone VI) has been found in every well studied and it probably occurs over the whole area of the county. It is a relatively thin zone consisting of coarsely crystalline limestone which is typically white in color.

In addition to the prevailing white color, a sample examiner will also find brown and black limestone as well as rarely pink and other colors. Furthermore, and very distinctive, this zone almost invariably contains large rounded windblown grains of quartz embedded in the limestone. This characteristic pertains especially to the lowest few feet of the zone. The presence of this sand suggests a possible unconformity between the Viola and the Simpson formation.

Zone V is the zone which is so often called Maquoketa by geologists and scouts. Ordinarily this zone consists of closely packed rhombs of the mineral dolomite which is brown in color. With the dolomite grains the samples show almost an equal amount of a peculiar smoky gray chert with dull luster. Locally, the dolomite grains appear scattered through a dark argillaceous material which then might be called shale. The dolomite grains appear as individuals and as bronze rhombs in a white or dirty gray matrix. Nevertheless, the typical chert,

[1] Manuscript received, December 4, 1947.

[2] Department of geology, University of Wichita.

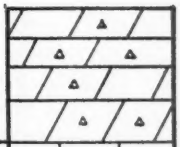
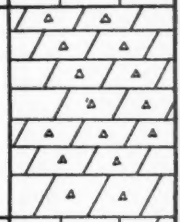
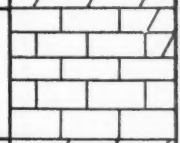
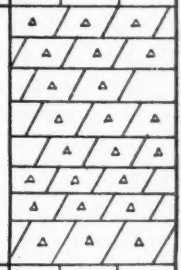
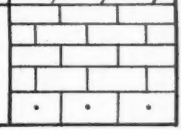
ZONE I	Cherty dolomite. Dolomite is brown chunky, finely crystalline. The chert is dull white or tripolitic. Average thickness 30 feet.	
ZONE II	Limestone. White and grey with brown spots. Average thickness 20 feet.	
ZONE III	Cherty dolomite. Dolomite is granular, buff, or finely crystalline or chunky. The chert is usually white or tripolitic, rarely blue. Average thickness 50 feet.	
ZONE IV	Same description as for Zone II. Locally crinoidal ls. Average thickness 30 feet.	
ZONE V	Dolomitic and cherty argillite. Scattered dolomite rhombs set in white or dirty matrix. Or dolomite may be even granular and microrhombohedral. The chert is usually dark grey, smoky grey, or speckled. Rarely blue. Average thickness 70 feet.	
ZONE VI	Limestone, coarsely crystalline, white with brown spots or splotches of grey or black - rarely pink or green. Locally some lithographic limestone. Sand - studded at base. Average thickness 20 feet.	

FIG. 1.—Zones in Viola limestone, Kansas.

as described, persists in this lithologic environment and the percentage also is nearly the same. The chert ordinarily makes up 40-60 per cent of the rock mass. Although the typical color of the chert is smoky gray, some wells contain black chert, some contain brown chert, and rarely bluish gray chert is present. The thickness of zone V in Barber County varies from 50 to 90 feet. Part of this varia-

tion is due to erosion and part is due to depositional conditions. Zone V has been found wholly or partly preserved in every well studied in Barber County.

From Barber County westward and northwestward, the lithologic peculiarity of zone V can be traced through Comanche, Edwards, Kiowa, and into Pawnee County. Northward it can be traced into Pratt County and eastward into Harper County. With slight facies modifications, this zone is the most distinctive unit in the entire Viola sequence. The thickness varies somewhat in the various counties enumerated.

Zone IV is a coarsely crystalline limestone with a typically white color. Commonly it is spotted or mottled with brown colors. The thickness of this zone varies from a thin wedge to 25 feet, partly on account of erosion. Most of the wildcat tests in Barber County show the whole or a remnant of zone IV in the well cuttings. Some of the wells on the Barber County arch in the northwestern part of the county reveal the Viola eroded down to zone IV and into the next lower zone.

Zone III is a cherty dolomite rock in which the dolomite is granular or finely crystalline and chunky. The color is commonly buff. The embedded chert is typically white opaque or it is tripolitic white. The chert content ranges from 40 to 60 per cent of the mass of the rock. The average thickness of this zone in Barber County is 40 feet. It is only found in the southwestern part of the county (T. 31 S., R. 14 W., and T. 31 S., R. 15 W.). At the west, zone III appears in Comanche County and at the northwest in Kiowa, Edwards, and Pawnee counties. In this area zone III is poorly represented because post-Ordovician erosion resulted in widespread solution of the calcareous material, leaving a thick mantle of detrital rubble. Nevertheless, some test holes reveal the zone intact.

On the north, in Pratt County, zone III is masked by the almost universal mantle of detrital material. However, in T. 26 S., R. 11 W., and T. 26 S., R. 12 W., and T. 26 S., R. 13 W., zone III was apparently preserved from destruction and can be found in the well cuttings.

Zone II is a coarsely crystalline limestone white or gray in color. In Barber County this zone was found only in T. 34 S., R. 14 W. Here all zones from II down to VI are preserved. The zone is also well preserved in parts of Comanche County. It may be seen in test wells in T. 33 S., R. 19 W., T. 34 S., R. 16 W., and in T. 35 S., R. 16 W. In Kiowa, Edwards, and Pawnee counties the general detrital condition of the whole Viola sequence masks the presence of this zone in the samples. Nevertheless, some wells in Edwards County show this zone in its preserved condition. Such are the tests in T. 23 S., R. 19 W., and T. 24 S., R. 19 W. In Pratt County only solution detritus was found at the level of zone II.

Zone I is a cherty dolomite rock which has a brown color and a chunky structure. It contains a large percentage of chert which is generally white opaque or tripolitic dull white. This zone is absent from test wells in Barber County, but present in a few wells in the adjoining Comanche County (T. 33 S., R. 19 W.). On the northwest it is present in a few wells in Edwards and in Pawnee counties.

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DISCUSSION

ATOKA OSTRACODES IN GLEN EYRIE FORMATION, COLORADO[1]

BETTY KELLETT[2]
St. Louis, Missouri

McLaughlin recently suggested[3] that a fauna found in the lower part of the Glen Eyrie formation in the Colorado Springs Quadrangle is Marmaton, upper Des Moines, in age. This fauna consists of about twelve species of ostracodes and eight of conodonts. McLaughlin was kind enough to send the writer the ostracodes, a beautiful fauna of many well preserved specimens. He did not, however, agree with the conclusions about their age. It is the writer's belief that they are much older than Marmaton and probably Atoka-Lampasas in age; they could only be older, or slightly younger, Morrow or earliest Cherokee in age.

Although the fauna is for the greater part undescribed, it is not unknown, for almost every one of the Glen Eyrie species is identical with, or close to, such Oklahoma Atoka or Wapanucka species as *Monoceratina ventrale* Roth, *Bairdia dornickhillensis* Harlton, *Amphissites wapanuckaensis* Harlton, and *A. rugosus* Girty. Another Glen Eyrie *Amphissites* is clearly the forerunner of *A. pinguis* (Ulrich and Bassler) (*A. geneae* Roth) of Marmaton and later age: the nodes which persist from the early to the late molts of the Glen Eyrie and similar pre-Des Moines specimens are lost in the latest molts of their Marmaton descendants. The Glen Eyrie species identified by McLaughlin with the upper Pennsylvanian species *Glyptopleura spinosa* Harlton (now called *G. coryelli* Harlton) shows a striking resemblence to *G. coryelli* in the rib arrangement and is undoubtedly related to it, but both the Glen Eyrie and certain pre-Marmaton specimens now being examined consistently show small but important differences from *G. coryelli:* besides differences in size and spine development the rib of the Glen Eyrie species is well arched above the muscle scar while this rib is bent downward on *G. coryelli. Geisina arcuata* (Bean) is probably correctly identified by McLaughlin but the given range is inaccurate as Bradfield found it to be characteristic of lower Dornick Hills beds of pre-Des Moines age. *Headia formosa* Harlton found in the Glen Eyrie is a much misunderstood species, Marmaton forms commonly referred to this species being much smaller and with much shorter spines, and in most cases referable to the Marmaton species *Healdia limacoidea* Knight. The type of *H. formosa* is probably not from Gaptank sediments, but, as suggested by Harlton in a footnote to his original description, it is probably Dimple (Morrow) in age.

The Wapanucka-Johns Valley fauna contains many large, fancifully ornamented ostracode species, of which the slightly more conservative descendents are found in Atoka faunas. Few of these species occur in the Marmaton, and this latter formation contains many Kansas City-Canyon species, so that the contrast between the two faunas is more marked than is ordinary between Pennsylvanian faunas of so nearly the same age. The Marmaton ostracodes are among the best known faunas, assemblages of this age having been described from Nebraska, Illinois, and Missouri, and down through Oklahoma and into Texas. Most if not all of the common and typical Marmaton species are absent in the Glen Eyrie formation; also absent is the Des Moines ostracode fauna (and signifi-

[1] Manuscript received, December 11, 1947.

[2] Mrs. E. H. Nadeau, Washington University.

[3] Kenneth P. McLaughlin, "Pennsylvanian Stratigraphy of Colorado Springs Quadrangle, Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 11 (November, 1947), pp. 1982–2020.

cantly all fusulinids) found in the McCoy formation of Colorado and described by Roth and Skinner.

An Atoka age for the Glen Eyrie beds is not surprising in view of the thick pre-Des Moines beds described by Maher and others from deep wells in westernmost Kansas and eastern Colorado. These beds are not lithologically unlike the Glen Eyrie, and they also contain early Pennsylvanian ostracodes.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

MESOZOIC FOSSILS OF THE PERUVIAN ANDES, BY MAXWELL M. KNECHTEL, EDWARD F. RICHARDS, AND MARY V. RATHBUN

REVIEW BY LEWIS B. KELLUM[1]
Ann Arbor, Michigan

"Mesozoic Fossils of the Peruvian Andes," by Maxwell M. Knechtel, Edward F. Richards, and Mary V. Rathbun. 150 pp., 24 figs., 50 pls. *The Johns Hopkins University Studies in Geology No. 15*, Ellsworth Expedition Publication (Baltimore, Maryland, 1947).

A systematic treatment of the invertebrate fossils collected chiefly by the Ellsworth Expeditions in 1924 and 1925, under the leadership of J. T. Singewald, Jr. Two additional collections by J. H. Sinclair and T. Wasson are also included. The fossils are from thirty-eight localities in the departments of Loreto, Huanuco, and Ancachs. They range in age from late Jurassic to mid-Upper Cretaceous. Age determinations of the fossil collections are as follows.

Upper Cretaceous	Senonian	Santonian
		Coniacian = Emscherian
Lower Cretaceous		Middle Albian
		Aptian
Upper Jurassic		Tithonian

Nearly half of the fossil collections, including all those determined to be Jurassic (Tithonian) and Aptian (Lower Cretaceous) and most of those determined to be Middle Albian, are from localities in western Peru in the department of Ancachs which is crossed by the Cordillera Occidental and the Cordillera Negra. Most of the Upper Cretaceous localities (Coniacian, Emscherian, Santonian, and Senonian) and three of the Lower Cretaceous (middle Albian) localities are in eastern Peru in the departments of Huanuco and Loreto, which are crossed by the Cordillera Central and the Cordillera Oriental.

Publication of the descriptions and figures of the fossils and their age significance is especially important at this time because of the discovery of oil in eastern Peru, in 1938, on the Agua Caliente anticline[2] in the department of Loreto, and the exploitation and exploration which have subsequently[3] taken place.

The paper is divided into four parts: Part I contains (1) a brief introduction (2 pages) by Knechtel and Richards, (2) a list of the collections, including (a) the collection number, (b) a list of species in the collection, and (c) the age of the beds as determined from the fossil assemblage, and (3) a description of collection localities by J. T. Singewald, Jr.; Part II is the systematic description of Echinoidea, Pelecypoda, and Gastropoda by Richards; Part III is the systematic description of the Cephalopoda by Maxwell; and Part IV is the systematic description of the Crustacea by Rathbun. Part IV is followed

[1] Museum of Paleontology, University of Michigan. Review received, November 10, 1947.

[2] R. G. Greene, "Oil on Agua Caliente Anticline, Department of Loreto, Peru," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 5 (May, 1939), pp. 688–90.

[3] L. G. Weeks, "Highlights on Developments in Foreign Petroleum Fields," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 7 (July, 1947), pp. 1156–57.

by (1) a bibliography of 84 items, (2) 10 pages of plate descriptions, and (3) 50 plates of fossils.

In Part II the systematic treatment of the Echinoidea includes the description of one new species and three new descriptions of species referred to previously known forms; 40 species of Pelecypoda are described of which 19 are new; and 9 Gastropoda of which 2 are new.

In Part III, 46 ammonite species are described, of which 25 are new. Part IV is the description of one new species of shrimp-like decapod from the Albian. The bibliography is limited to paleontological publications, the latest of which is 1932. The paper is excel-

Time		*European Stages*	*Pongo de Mansericbe (Singewald, 1927)*	*Pichis and Pachitea Rivers (Moran and Fyfe, 1933)*	*Ucayali River and Eastward (Oppenheim, 1937)*
Quaternary			?	Arcillas Rojas ?	
Tertiary	Pliocene Miocene Oligocene Eocene		Brown beds 3,000 feet ?	Capas Morenos ?	?
Mesozoic	Upper Cretaceous	Maestrichtian			
		Senonian: Campanian	Red beds 4,000 feet	Arenisca de Puca 5,000 feet	Cruzeiro Red beds 500 feet ?
		Senonian: Santonian			
		Senonian: Coniacian (Emscherian)	? Huacanqui sandstone	Arenisca de Azucar 500 feet ?	Sungaru sandstone 500 feet ?
		Turonian			
		Cenomanian	Shale-limestone series	Caliza de Chonta 1,300 feet	Shale-limestone series 1,000 feet
	Lower Cretaceous	Albian	?	?	?
		Aptian	?	?	?
		Neocomian	Pongo sandstone ?	Arenisca de Agua Caliente 1,000 feet ?	Moa sandstone ?
	Jurassic	Tithonian			

lently illustrated with plates of fossils printed by the collotype process. Part III is also illustrated by numerous line drawings of ammonite sutures.

The significance of this paper is best understood and appreciated if it is recognized to be the paleontological part of a much larger contribution to the geology of Peru. Four previous publications by J. T. Singewald, Jr., have presented the stratigraphy and structural geology of the areas where these fossils were collected. The first[4] gives a general description of geologic observations made along the route of the Ellsworth Expedition across successive ranges of the Andes from the Pacific Ocean on the west to the Amazon drainage basin on the east. The second[5] describes the geology of the Pongo de Manseriche, a canyon cut by the Rio Marañon through the eastern range of the Andes. The third[6]

[4] J. T. Singewald, Jr., "The Ellsworth Expedition of The Johns Hopkins University to the Peruvian Andes," *Bull. Pan Amer. Union*, Vol. 59, No. 3 (March, 1925), pp. 254–62.

[5] J. T. Singewald, Jr., "Pongo de Manseriche," *Bull. Geol. Soc. America*, Vol. 38, No. 3 (September, 1927), pp. 479–92.

[6] J. T. Singewald, Jr., "Geology of the Pichis and Pachitea Rivers, Peru," *Bull. Geol. Soc. America*, Vol. 39, No. 2 (June, 1928), pp. 447–64.

describes the geology of the Pachitea River and its tributary Rio Pachis which flow northeastward across the Cordillera Oriental into the Rio Ucayali. The fourth[7] is a discussion and correlation of his previous work with that of Victor Oppenheim in the Cordillera Oriental and farther east. In the latter paper Singewald gives the age and stratigraphic succession and thickness of formations in the Cordillera Oriental, from which about half of the fossils described by Knechtel, Richards, and Rathbun were obtained. The accompanying table, compiled to show the stratigraphic position of the fossil collections, is based on information given in Singewald's discussion.

[7] J. T. Singewald, Jr., Discussion of "Geological Exploration between Upper Jurua River, Brazil, and Middle Ucayali River, Peru," by Victor Oppenheim, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 10 (October, 1937), pp. 1347–51.

GUIDEBOOK, 1947 FIELD CONFERENCE IN THE BIGHORN BASIN, WYOMING

REVIEW BY D. L. BLACKSTONE, JR.[1]
Laramie, Wyoming

Guidebook, 1947 Field Conference in the Bighorn Basin, Wyoming. 277 pp., 3 folded maps, 1 folded correlation chart, 1 pl. physiographic diagram, 14 pp. photographs, 9 pls. stratigraphic columns, 17 geologic maps, 4 electric-log stratigraphic sections, 5 cross sections. Bibliography follows each paper, perforated spiral-bound, manila cover, plastic binder, 8.5 by 11 inches. Published by the University of Wyoming, Wyoming Geological Association, and the Yellowstone-Bighorn Research Association. For sale by the Wyoming Geological Association, Casper, Wyoming. Price, $4.00.

This volume is the guidebook published for the second Annual Field Conference of the Wyoming Geological Association, cooperating with the University of Wyoming and the Yellowstone-Bighorn Research Association, acting as joint hosts to the Geological Society of America. The conference was organized under the guidance of the following committees: co-chairmen, H. D. Thomas, J. R. Fanshawe, and W. T. Thom, Jr.; registration, W. S. Knouse; caravan, Emmett Schieck; editors, D. L. Blackstone, Jr., and C. W. Sternberg.

The conference program was organized to first give an over-all view of the intermontane basin to be studied by means of a 2-day circuit of the entire area. The excursions of the latter 2 days were organized to allow participants to visit areas of special interest to the individuals concerned. The guidebook reflects this organization in that the first section is devoted to detailed road logs of the conference excursions, followed by exit logs for all principal routes leading into the region.

Fourteen pages of photographs of significant geologic localities shown both by conventional horizontal photographs and vertical aerial views follow the road logs. The use of aerial photographs to show locations visited is very effective.

The major part of the conference guidebook consists of 162 pages of special papers arranged to develop the geological history of the region. The topics discussed begin with physiography, followed in logical order by stratigraphy by geologic eras, regional structural features, local structural features, detailed geology of significant producing fields, statistical data on the fields, and concludes with a glossary of formation names.

The titles and authors of papers are listed in the order in which they appear in the guidebook.

[1] Department of geology, University of Wyoming. Review received, November 6, 1947.

"Altitude and Local Relief of Bighorn Area during the Cenozoic," J. Hoover Mackin; "Paleozoic Formations of the Bighorn Basin," T. F. Stipp; "Mesozoic Stratigraphy of the Bighorn Basin Area," George R. Downs; "Early Tertiary Stratigraphy and Correlations," Glenn L. Jepsen, and Franklyn B. Van Houten; "Results of Some Heavy-Mineral Studies in the Bighorn Basin, Montana and Wyoming," Marcellus H. Stow; "Absaroka Volcanic Field," John T. Rouse; "Structural Features of the Bighorn Basin Rim," W. T. Thom, Jr; "Tectonic Development of the Bighorn Basin," John R. Fanshawe; "Structural Relationships of the Pryor Mountains," D. L. Blackstone, Jr.; "Heart Mountain Problem," Walter H. Bucher.

The summary of the physiographic history of the region by Mackin in terms of a pediment development rather that the classic peneplain treatment is clearly presented. The sub-summit surface is viewed by Mackin as a pediment developed at a high level in relation to stream slopes. The role of climatic variation in Tertiary time is stressed, and the concept of extensive peneplanation in Eocene time is discounted. The Tertiary history of the ranges is logically interpreted in terms of the waste they supplied and which was deposited on the Great Plains.

The stratigraphy of the Bighorn basin is presented by Stipp, Downs, Jepsen and Van Houten, Stow, and Rouse. The Paleozoic section is described and correlated throughout the basin in a combination of measured surface sections and electric logs of subsurface sections. The Mesozoic history is presented in terms of the regional depositional history rather than as a statistical review of measured sections. The presentation of data in terms of a depositional concept will do much to clarify stratigraphic problems. Jepsen and Van Houten present the evidence for the subdivision of the early Tertiary sediments in light of both the lithologies involved, and the vertebrate faunas. The writers have pointed out rather forcefully the confusion in the application of names to lithologic units of continental environments of deposition. The widespread application of such names to areas that had quite different depositional histories is discouraged. Particularly interesting in their paper is the summary of the stratigraphic section in the vicinity of Polecat Bench from which the extensive vertebrate fauna has been collected.

The use and relationships of heavy-mineral suites in areas of continental deposition is pointed out by Stow.

The volcanic sequence of the Absaroka volcanic field, its mode of occurrence and regional structural relationships are summarized by Rouse from his extensive work in the region.

The section on structural geology consists of a broad outline of the structural features, the tectonic development of the Bighorn basin, followed by two papers on specific features. Bucher has presented a brief summary of part of his views concerning the Heart Mountain problem, and includes his interpretation of the South Fork thrust.

A summary of the history of exploration in the Bighorn basin by C. J. Hares introduces the part of the guidebook devoted to detailed data on the individual oil-producing areas. The detailed papers are listed herewith.

"History of the Oil Business in the Bighorn Basin," C. J. Hares; "Oregon Basin Field," Paul T. Walton; "Grass Cree Oil Field," Rolland W. McCanne; "Hamilton Dome," E. W. Krampert; "Basin Oil and Gas Field," T. C. Hiestand; "Frannie Oil Field," A. E. Brainerd, Stuart L. Carter, and Bruce F. Curtis; "Elk Basin Anticline," W. S. McCabe; "Embar and Tensleep Crude Oil Gravities," Penn L. Gooldy; "Bighorn Basin Crude Oil Production," Maury and Bill Goodin; "Catalog of Formation Names of Bighorn Basin and Adjacent Areas," R. L. Sielaff.

The papers include stratigraphic sections, type electric logs, structure-contour maps, production data, and statistics. The section is concluded by an analysis of crude-oil gravities in relation to depth, and a section presenting production statistics for all Bighorn basin fields since discovery.

A revised structural contour map of the Bighorn basin prepared by W. G. Pierce,

David A. Andrews, and Jewell Kirby Keroher, using the Frontier sandstone as a datum was supplied through the courtesy of the United States Geological Survey. On this base were placed all roads, conference routes, stops, and towns. This large map, with the geologic structure shown was very useful in visualizing the space relationships of the areas visited.

The guidebook is particularly noteworthy in that it presents to the geological profession a coordinated study of a structural basin in which more than half of the material was contributed by men actively engaged in petroleum exploration. Much credit is therefore due to the several oil companies in the area who encouraged their representatives to join with the academic and United States Geological Survey geologists in its preparation.

BIBLIOGRAPHY AND INDEX OF PUBLICATIONS RELATING TO GROUND WATER PREPARED BY THE GEOLOGICAL SURVEY AND COOPERATING AGENCIES, BY G. A. WARING AND O. E. MEINZER

REVIEW BY JOHN C. MAHER[1]
Tulsa, Oklahoma

*"Bibliography and Index of Publications Relating to Ground Water Prepared by the Geological Survey and Cooperating Agencies," by Gerald A. Waring and Oscar E. Meinzer. *U. S. Geol. Survey Water-Supply Paper 992* (1947). 412 pp. Price, $1.00.

Water Supply Paper 992 is the third compilation of publications relating to ground water by the United States Geological Survey. The first, prepared by M. L. Fuller[2] and published in 1905 as Water-Supply Paper 120, listed only those papers published by the United States Geological Survey; the second, prepared by O. E. Meinzer[3] and published in 1918 as Water-Supply Paper 427, included 12 reports published by cooperating agencies as well as 609 reports published by the U. S. Geological Survey. The present edition, compiled by G. A. Waring and O. E. Meinzer with the assistance of K. E. Anderson, C. L. McGuinness, and J. M. Berdan, lists 1,777 papers which include 919 publications of the U. S. Geological Survey, 276 cooperative reports published by cooperating state, municipal, and other governmental agencies, 290 short reports mimeographed or otherwise duplicated by the Geological Survey, and 373 articles relating to ground water written by members of the Geological Survey and published in scientific, technical, and trade journals. These papers, with brief abstracts or notations for each, are grouped under the following headings, the variety of which illustrates the broad overlap of ground-water studies into all phases of geology: Water-supply papers, Annual reports, Monographs, Professional papers, Bulletins, Mineral resources, Geologic folios, Reports published by cooperating agencies, Mimeographed and other duplicated reports, and Journal articles. An extensive and easily read index of subjects and authors is appended.

Much original geologic work is contained in water-supply papers and some of them contain the only subsurface data available for large areas. Therefore this volume should prove

[1] Geologist, United States Geological Survey, Published by permission of the director. Review received, December, 9, 1947.

[2] M. L. Fuller, "Bibliographic Review and Index of Papers Relating to Underground Waters published by the United States Geological Survey, 1879–1904," *U. S. Geol. Survey Water-Supply Paper 120* (1905).

[3] O. E. Meinzer, "Bibliography and Index of the Publications of the United States Geological Survey Relating to Ground Water," *U. S. Geol. Survey Water-Supply Paper 427* (1918).

very useful not only to ground-water geologists and engineers but also to petroleum geologists, particularly those who are engaged in reconnaissance work in states which have not been actively explored for oil. An index map, or several maps, similar to the one in Water-Supply Paper 427 showing the areas covered by water-supply papers and a strict chronological order of journal articles might facilitate the finding of references. The revision of this bibliography and index at ten-year intervals in the future would seem desirable.

RECENT PUBLICATIONS

ALABAMA

"Profiles Showing Geology along Highways in the Vicinity of Tuscaloosa, Alabama," by D. Hoye Eargle. *U. S. Geol. Survey Prelim. Chart 31*, Oil and Gas Inves. Ser. (December, 1947). Single sheet, 32×53 inches. 5 profiles on vertical scale of 1 inch equals 75 feet, and horizontal scale of 1 inch equals 1,500 feet. Key map scale, 1 inch equals 4 miles. For sale by Director, Geological Survey, Washington 25, D. C. Price, $0.50.

CANADA

*"Reconnaissance Geology of Portions of Victoria Island and Adjacent Regions, Arctic Canada," by A. L. Washburn. *Geol. Soc. America Mem. 22* (New York, October 20, 1947). 14 pp., 32 pls., 4 figs.

COLORADO

*"Colorado Drainage Basin," by Herbert E. Gregory. *Amer. Jour. Sci.*, Vol. 245, No. 11 (New Haven, Connecticut, November, 1947), pp. 694–705.

*"Progress of Mining Studies at Bureau of Mines Oil-Shale Mine, Anvil Point, Rifle, Colorado," by E. D. Gardner. *Mining Technology*, Vol. 11, No. 6 (New York, November, 1947). 11 pp., 4 figs. *A. I. M. E. Tech. Pub. 2286.*

CUBA

**Croquis Geologico de Cuba* (Geological Map of Cuba), by the Geological Map Commission: Jorge Brodermann, Jesús Fco. de Albear, and Ormando Andreu. Comisión Geológica de Cuba, Habana (June, 1946). Sheet in colors, approx. 48.5×19.5 inches. Scale, 1:1,000,000.

**Mapa Minero* (Minerals Map), by the Geological Map Commission: Antonio Calvache, Jorge Brodermann, and German Alvarez Fuentes. Comisión Geológica de Cuba, Habana (1947). Sheet in colors, approx. 48.5×19.5 inches. Scale, 1:1,000,000.

CZECHOSLOVAKIA

*"Geologia Strednej Časti Strážovskej Hornatiny" (Geology of the Middle Part of the Strazov Mountains), by M. Mahel. *Práce Štátneho Geologického Ústavu Sošit 14 (Geological Survey Pub. 14*, Bratislava, 1946). 116 pp., 4 figs., 7 folded inserts (geologic sections and maps), 3 photographs. Pp. 93–113, French résumé of Slovakian text by Valentine Andrusov.

GENERAL

*"What Does Industry Have a Right to Expect of Petroleum Engineering Schools?" by P. H. Bohart. *Petrol. Tech.*, Vol. 10, No. 6 (New York, November, 1947). 6 pp. *A. I. M. E. Tech. Pub. 2270.*

When the Oil Wells Run Dry, by Walter M. Fuchs. 447 pp., 79 illus. cloth. Industrial Research Service, Masonic Building, Dover, New Hampshire. Price, $4.50.

*"Intertonguing Marine and Nonmarine Upper Cretaceous Deposits of New Mexico, Arizona, and Southwestern Colorado," by William S. Pike, Jr. *Geol. Soc. America Mem. 24* (New York, October 15, 1947). 103 pp. 7 figs., 12 pls.

Mines Magazine (November, 1947). 12th annual petroleum number. 100 pp., 48 illus., 8 drawings, 7 maps, 2 tables. Frank C. Bowman, editor, 734 Cooper Building, Denver 2, Colorado. Official organ of Colorado School of Mines Alumni Association. Price, $1.00.

*"Some Desirable Improvements in Core Barrels," by George D. Roberts. *Mining Technology*, Vol. 11, No. 6 (New York, November, 1947). 7 pp., 2 figs. *A. I. M. E. Tech. Pub. 2275.*

*"Educating and Training Economic Geologists of the Future," by Charles H. Behre, Jr. *Ibid.* 10 pp., 1 table. *A. I. M. E. Tech. Pub. 2285.*

**Water Well Handbook*, by Keith E. Anderson. 200 pp. Illus. Planographed. 5.5×8.5 inches. Paper cover. Published by Missouri Water Well Drillers Association, Box 250, Rolla, Missouri. Price, $1.50.

GERMANY

**Geotectonic Map of Northwest Germany*, prepared by Geologisches Landesamt, Hanover (1945–1946), by order of British Oil Fields Investigation, 912 Military Government Celle (1946). Compiled from geological and geophysical data obtained from surveys and drilling for oil and iron ore from 1934 to 1945. Scale, 1:100,000. 25 sheets, each 56×67 centimeters (approx. 26.5×30 inches). Limited supply available for distribution from W. L. F. Nuttal, Petroleum Division, 7 Millbank, London, SW. I, England.

GULF OF MEXICO

*"Catastrophism in the Sea and Its Paleontological Significance, with Special Reference to the Gulf of Mexico," by Gordon Gunter. *Amer. Jour. Sci.*, Vol. 245, No. 11 (New Haven, Connecticut, November, 1947), pp. 669–76.

*"Geological Study of Gulf Coast Continental Shelf to Its Edge Is Goal of Project Now under Way," *Anon. Oil and Gas Jour.*, Vol. 46, No. 32 (Tulsa, November 13, 1947), pp. 82–87; 8 photographs, 2 figs.

IOWA

*"The Iowan Drift Border of Northwestern Iowa," by Guy D. Smith and F. F. Riecken. *Amer. Jour. Sci.*, Vol. 245, No. 11 (New Haven, Connecticut, November, 1947), pp. 706–13; 1 fig.

KANSAS-COLORADO

*"Subsurface Geologic Cross Section from Trego County, Kansas, to Cheyenne County, Colorado," by Jack B. Collins. *Kansas Geol. Survey Oil and Gas Inves. Prelim. Cross Sec. 5* (Lawrence, 1947). Prepared by U. S. Geol. Survey with cooperation of State Geol. Survey of Kansas. Sheet, 39×28.5 inches, 8 pp. text.

OKLAHOMA

*"A Reservoir Study of the West Edmond Hunton Pool, Oklahoma," by Max Littlefield, L. L. Gray, and A. C. Godbold. *Petrol. Tech.*, Vol. 10, No. 6 (New York, November, 1947). 34 pp., 14 figs., 4 tables. *A. I. M. E. Tech. Pub. 2203.*

POLAND

**Rocznik Polskiego Towarzystwa Geologicznego*, Tom XVI, 1946 (*Annals, Geological Society of Poland*, Vol. 16, Kraków, 1946). Memorial volume to Jan Nowak. 252 pp. Contains 7 articles in Polish with French and English résumés:

1. F. Bieda: Stratigraphy of Flysch of Central Polish Carpathians, Based on Foraminifera.
2. E. Passendorfer: Geological Structure of Wilno.
3. A. Jahn: Stratigraphy of Quaternary in Bug River Basin.
4. M. Rozkowska: Silurian Rugose Corals from Podolia.
5. K. Smulikowski: Dolomite of Imielin (Upper Silesia).
6. E. Passendorfer and J. Zablocki: Tertiary and Quaternary of Baltic Coast between Wielka Wies and Jastrzebia Gora.
7. W. Szafer: Development of Holarctic Flora.

TENNESSEE

*"The Oil Prospects of West Tennessee," from data assembled by Abe L. Roberts. *Oil*, Vol. 7, No. 5 (New Orleans, Louisiana, November, 1947), pp. 12–14, 25–27; 3 photographs, 1 map.

TURKEY

*"A Preliminary Note on Fossiliferous Upper Silurian Beds near Eregli," by Recep Egemen. *Türkiye Jeoloji Kurumu Büllini* (Bull. Geol. Soc. Turkey), Vol. 1, No. 1 (M. T. A. Enstitüsü, Ankara, October, 1947), pp. 53–59. In English.

*"Relations géologiques entre la Turquie et les regions pétrolifères en Europe orientale et en Asie occidentale" (Geological Relations between Turkey and the Petroliferous Regions in Eastern Europe and in Western Asia), by E. Lahn. *Ibid.*, pp. 120–33. In French.

*"New Fossiliferous Beds in Kocaeli Triassic Formations," by Kemal Erguvanli. *Ibid.*, pp. 161–63. In English.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 1 (JANUARY, 1948), PP. 139-144

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The committee has completed its preliminary investigation of prospective attendance at the convention, and will soon send out a second card, requesting that the membership make choice of hotel accommodations and field trip preference.

N. W. Bass, chairman of the technical program, announces no papers can be included in the program later than February 20, due to restrictions by the printer.

ADDITIONAL APPLICATIONS APPROVED FOR PUBLICATION

(continued from page 143)

FOR ACTIVE MEMBERSHIP

Jack Wilson Craig, Houston, Tex.
P. B. Leavenworth, Marcus A. Hanna, Leslie J. Franz
Wolf Maync, Caracas, Venezuela, S. A.
Hans E. Thalmann, H. H. Renz, D. W. Gravell
Simon Papp, Budapest, Hungary
Lewis G. Weeks, Ray P. Walters, Winthrop P. Haynes
Robert Emmett Roark, Midland, Tex.
Robert I. Dickey, Harold L. Huffman, Peter P. Gregory
Erwin Charles Stumm, Ann Arbor, Mich.
Lewis B. Kellum, A. J. Eardley, K. K. Landes
Alvin Dale Turquette, Bartlesville, Okla.
Paul L. Bartram, Edwin I. Thompson, W. B. Weeks
William Frederick Wrath, Los Angeles, Calif.
Sam Stewart, Clifton W. Johnson, Hampton Smith

FOR ASSOCIATE MEMBERSHIP

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P. E. Nolan, George L. Lockett, H. H. Renz
William Dwight Davis, Mt. Vernon, Ill.
E. E. Rehn, A. B. Carlisle, C. F. Passel
Richard Lyle Enyert, Ann Arbor, Mich.
K. K. Landes, A. J. Eardley, R. C. Hussey
Jesse L. George, Jr., Houston, Tex.
George I. McFerron, Merle C. Israelsky, Donald Crary
Frank Delno Holland, Jr., Lawrence, Kan.
L. R. Laudon, C. G. Lalicker, John C. Frye
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A. R. Winzeler, V. G. Hill, B. F. Murphy
Robert Elton Hunt, Columbus, Ohio
Donald L. Norling, C. H. Summerson, Edmund M. Spieker
Douglas Lamar Inman, La Jolla, Calif.
Francis P. Shepard, K. O. Emery, R. Dana Russell
David Lee Minard, Lake Charles, La.
W. Farrin Hoover, Harold R. Wanless, H. W. Scott
W. C. Osborne, Midland, Tex.
F. H. McGuigan, W. D. Henderson, R. E. Le Blond
Louie Sebring, Jr., San Antonio, Tex.
Douglas Weatherston, Morris C. Minton, Ira H. Stein

FOR TRANSFER TO ACTIVE MEMBERSHIP

Jack Nickerson Darling, Houston, Tex.
J. Brian Eby, J. U. Teague, Joseph Zaba

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 1 (JANUARY, 1948), PP. 145-147, 1 FIG.

MEMORIAL

KENDALL EUGENE BORN
(1908–1947)

Kendall E. Born was teaching geology at Missouri School of Mines, Rolla, Missouri, at the time of his death, September 21, 1947, but it was during his long association with the Tennessee Division of Geology that the personal and professional contacts were made that resulted in his widespread acquaintances and reputation in geological circles. He died at the Missouri Baptist Hospital in St. Louis, Missouri, and was buried in his home town of Chester, Illinois. His early school work was done in Chester where he was born, February 15, 1908. In 1930 he graduated from McKendree College, Lebanon, Illinois, with the degree of Bachelor of Science. He attended Vanderbilt University, Nashville, Tennessee, receiving the Master of Science degree in 1931, presenting a report on the brown iron ore of the Western Highland Rim for his thesis. He returned to Vanderbilt for the

school year 1931–1932 for additional courses in geology. During his two years at Vanderbilt he was a Graduate Fellow. The writer started teaching at Vanderbilt in the Fall of 1931, and rarely has it been the privilege of a beginning instructor to have such excellent students as Kendall, Robert Ross, and Ernest Spain in his first class in stratigraphy. In 1932–1933 Kendall was Von Blarcom Fellow in Geology at Washington University, St. Louis, and in 1933–1935 he was a graduate assistant there. During the period of his education Kendall enjoyed the friendship and respect of his fellow students, and earned the high esteem and personal affection of his instructors.

During the summers of 1933 and 1934 Kendall was employed by the Tennessee Division of Geology to do areal geologic mapping in Dickson County. There he had opportunity to continue his study of brown iron ore and the Tuscaloosa gravel which he started as a graduate student at Vanderbilt. His interest in the Mississippian system dates from these summers. In February, 1935, he accepted full-time employment with the Division with the rank of assistant geologist. Here he remained until November, 1946, at which time he resigned to accept an assistant professorship at the Missouri School of Mines, the position he held at the time of his death. There within one year Kendall had established himself with his students as a personal and professional friend and a stimulating teacher. During his tenure with the Division of Geology he advanced from his beginning rank of assistant geologist to associate geologist in 1939 and to assistant State geologist in 1945. His chief duties during this period related to oil and gas investigation and development. It was largely in this capacity that he became known and respected by many petroleum geologists. Visitors to his office were all impressed by his willingness to assist them as much as possible, giving freely of his time and knowledge, and by his remarkable ability to remember faces and facts. In this capacity, and in his attendance at national professional meetings, in field conferences, and in professional travel, his personality and his knowledge of geology, geological literature, and geologists made him one of the most widely liked and respected geologists. In addition to his oil and gas work many other duties and responsibilities came his way during the twelve years with the Division of Geology—compilation of the mineral resources of the state, red iron ores of eastern Tennessee, chemical limestone, and geology and oil and gas possibilities of Clay County and other parts of the state. His long bibliography speaks for itself in regard to his work in geology.

In 1937 Kendall was elected to associate membership in the American Association of Petroleum Geologists, and in September, 1938, was transferred to full membership. He was an enthusiastic member and always looked forward to the annual meetings where he could associate personally and professionally with his many friends and could make new friends. In December, 1945, he was elected Fellow of the Geological Society of America. He also belonged to the Paleontological Society, Society of Economic Paleontologists and Mineralogists, American Geophysical Union, Mineralogical Society of America, American Institute of Mining and Metallurgical Engineers, Sigma Xi, and Sigma Zeta. During his stay in Tennessee Kendall was active in the Tennessee Academy of Science, serving as secretary-treasurer from 1940 to 1946. He was one of the leaders in the establishment of the Section on Geology and Geography. Kendall presented many papers on aspects of the geology of Tennessee at the meetings of his professional societies. He was especially sought as speaker at regional meetings of geological societies affiliated with the American Association of Petroleum Geologists. One of the high points of recognition in his career occurred in November, 1942, when he became the first speaker on the Distinguished Lecture tour of the American Association of Petroleum Geologists. His two lectures were "The Pre-Cretaceous Rocks in the Northern Part of the Mississippi Embayment" and "History of Oil and Gas Exploration in Tennessee" and were very well received.

In February, 1936, he married Hazel Gentry, an attractive sensible young lady and a talented musician. They had two sons, Michael, aged 10, named after Kendall's father, and Kenny, aged 9, named for Kendall. The four composed a happy family, as the many

geologists and others who were entertained in their home can testify. Kendall's major interests were his family, geology, and geologists, but his minor ones were many and varied. He had a keen appreciation of music, being particularly well versed in symphonic recordings and in the development of American jazz. Medicine interested him and he stayed abreast of the advances of the medical profession. The book *Mutiny on the Bounty* fascinated him so much that he collected an extensive library on the subject, corresponding with the authors in regard to details. Geological personalities and the human factors that form the background for many geological events intrigued him. Wide interest in these and many other subjects mingled with a limitless store of jokes and anecdotes—always well told—made him an entertaining conversationist at all times and good company in the field.

Kendall will be missed by all of us.

CHARLES W. WILSON, JR.

Nashville, Tennessee
October 21, 1947

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 1 (JANUARY, 1948), PP. 148-152

AT HOME AND ABROAD

NEWS OF THE PROFESSION

HOWARD C. PYLE has resigned as vice-president of the Bank of America, at Los Angeles, California, to become president of the Continental Consolidated Corporation.

The Branner Geological Club held its first dinner meeting of the season on October 8, 1947, at the Athenaeum of California Institute of Technology. GORDON A. MACDONALD, of the University of Southern California, spoke on "Hawaiian Volcanoes" and showed spectacular, colored movies of eruptions. One hundred and one members and guests attended. Any geologist in the Los Angeles area not now on the mailing list may receive notice of future meetings by notifying the secretary-treasurer and enclosing one dollar for annual dues. Address W. H. EASTON, Box 100, University of Southern California, Los Angeles 7, California.

E. D. LYNTON, oil consultant for the French Government, presently associated with the Institut du Petrole des Carburants et Lubrifiants, on matters relating to their oil exploration and development program, has just received one of the highest honors that can be conferred upon a foreigner by the Sultan of Morocco. He was advised on November 7 that the Moroccan Government had decorated him with the order of "Commander of Ouissam Alaouite" for meritorious work in the years 1943 and 1944.

GEOFFREY BARROW has changed his address from the Tropical Oil Company, Bogota, Colombia, to the International Petroleum Company, Ltd., Toronto, Canada.

NORMAN F. WILLIAMS recently left his position as instructor in geology at the University of Oklahoma to accept the position of associate geologist with the Arkansas Geological Survey in Little Rock.

RAYMOND C. ROBECK has resigned from the Amerada Petroleum Corporation to accept a position with the United States Geological Survey.

Speakers at meetings of the Oklahoma City Geological Society in recent months include the following: CARL A. MOORE, associate professor of geology at Oklahoma University, Norman, on "The Electronic Microscope, Its Use and Application," L. H. HUMPHREY, the Shell Oil Company, on "Prospecting for Petroleum," and J. M. PARKER, of the Stanolind Oil and Gas Company, on "Prospecting for Petroleum in the Northwest Territories."

The new officers of the United States Section of the Pan American Institute of Mining Engineering and Geology are: W. D. JOHNSTON, JR., United States Geological Survey, Washington, D. C., chairman; FRANCIS CAMERON and GEORGE M. KNEBEL, vice-chairmen; EDWARD J. CRAIG, Harmon-on-Hudson, New York, secretary-treasurer. The next meeting will be in conjunction with the A. I. M. E. in New York in February, 1948, when a program of papers on Latin America will be presented. The annual luncheon will be held at that time. Plans are being made for the 3d Congress of Pan American Mining Engineering and Geology to be held in the United States in 1949. The 1st Congress met in Santiago, Chile, in 1942, and the 2d Congress in Rio de Janeiro, Brazil, in 1946.

L. F. McCOLLUM, co-ordinator of production of the Standard Oil Company (New Jersey), has been elected president of the Continental Oil Company, succeeding Dan Moran.

S. LLOYD STONEHAM has terminated his connection with the Sun Oil Company in McAllen, Texas, and is now with the Jergins Oil Company, City National Bank Building, Houston, Texas.

REGINALD G. (REX) RYAN announces the removal of his office to Cortez, Colorado, where he will engage in consulting geology.

SAM KORNFELD has opened his office for consulting geology at 523 Hales Building, Oklahoma City, Oklahoma.

PERCY L. PROSIT has left the Merrille Drilling Company, Mt. Pleasant, Michigan, to become district geologist for the Mid-Continent Petroleum Corporation, Abilene, Texas.

ROBERT P. MCNEAL has resigned from the Shell Oil Company, Inc., and is now with the Missouri Geological Survey at Rolla, Missouri.

M. H. S. BARKER, formerly with the Anglo-Egyptian Oil Fields, Ltd., is with the United British Oilfields of Trinidad, Limited, Point Fortin, Trinidad, B. W. I.

ROBERT HENDRICKSON, formerly with the Tide Water Associated Oil Company, is district geologist for the Union Oil Company of California, Corpus Christi, Texas.

DEWITT C. VAN SICLEN is now with Drilling and Exploration Company, Inc., at 158½ Cypress Street, Abilene, Texas.

New officers of the Pacific Section of the Association at Los Angeles, are: president, WILLIAM P. WINHAM, Standard Oil Company of California; vice-president, HARVEY W. LEE, Union Oil Company of California; secretary-treasurer, P. H. GARDETT, General Petroleum Corporation.

The second annual meeting of the Geological Society of Turkey was held in Ankara, October 30, and November 1. The new executive committee is composed of the following: president, HAMIT N. PAMIR; vice-president, RECEP EGEMEN; secretary, MELIH TOKAY; treasurer, MEHLIKA TASMAN; executive member, CEVAT TASMAN.

ABDUL K. META, recently managing director of Marks Brothers, Ltd., consulting geologists and mining engineers in Calcutta and Delhi, has accepted appointment with the Kalat State Government as State geological engineer and secretary of the Department of Mines and Development. His address is Kalat, Kalat State (Baluchestan), Pakistan.

JOHN W. BRICE, who for the last twenty years has been engaged in exploration and producing activities of the Standard Oil Company (New Jersey) and affiliates, has been appointed coordinator of producing activities for the company. He succeeds L. F. McCOLLUM who has resigned to become president of the Continental Oil Company.

GEORGES PARDO has moved from the Mene Grande Oil Company, Caracas, Venezuela, to the Gulf Oil Corporation, New York City.

The fiftieth anniversary of the West Virginia Geological Survey was celebrated on December 5, 1947, by a joint meeting with the Appalachian Geological Society of Charleston, West Virginia, and the Oil and Gas Section of the Engineers Society of Western Pennsylvania, Pittsburgh, Pennsylvania. The toastmaster for the dinner at the Morgan-

town Country Club was GORDON GULLEY of the Gulf Oil Company, Pittsburgh. PAUL H. PRICE, State geologist, reviewed the history of the Survey and give future aims. Comments will be made by several speakers, including DEWITT T. RING, vice-president, Columbia Oil and Gasoline Subsidiary Company.

HEDWIG T. KNIKER, who is connected with the Chilean Government's oil exploration program in Magallanes Province, southern Chile, and who has been in the States on vacation the past 2 months, has returned to Punta Arenas, Chile.

GARALD G. PARKER, United States Geological Survey (Water Supply) geologist-in-charge at Miami, Florida, has been elected vice-president of the Florida Academy of Sciences at its annual meeting held recently in Tallahassee. At the same meeting Parker read a paper on the "Response of the Water Table in Southern Florida to Earthquakes, Passing Trains, Winds, Tides, and Barometric Pressure Changes."

ROBERT B. CAMPBELL, consulting geologist of Gulf Hammock, Florida, read three papers at the recent annual meeting of the Florida Academy of Sciences at Tallahassee. Titles were: "The Changing Picture in World Oil," "Seismology in Florida," and "*Mesocricetus auratus auratus*, a New Laboratory Animal."

The Rocky Mountain Association of Geologists, Denver, Colorado, presented the following program on December 9: "Comments on the Dry Hole on Coal Creek Anticline," by KENNETH GOW; "Comments on the Dry Holes on Poose Creek and Yellowjacket Anticlines," by B. E. ASHLEY; "Freezeout Creek Fault, Baca County, Colorado," by K. M. BUEHLER.

BETTY A. ELLIOTT, nee Baker, is associated with the Topographical Branch of the United States Geological Survey in Denver, Colorado.

J. M. PARKER, of the Stanolind Oil and Gas Company, Casper, Wyoming, presented a paper on "Prospecting for Oil in Northwest Territories, Canada," at the meeting of the Tulsa Geological Society, December 1.

HUGH JAMES MCKAY, aged 62 years, geologist and oil operator of Sapulpa, Oklahoma, died at Earltown, Nova Scotia, November 27.

C. E. NEEDHAM of the United States Bureau of Mines, Salt Lake City, Utah, spoke on "Utah's Hundred Years of Mineral Production" before the Utah Academy of Sciences, November 1, and the class in mining seminar at the University of Utah, December 5.

WORTH W. MCDONALD, district geologist for the Arkansas Fuel Oil Company for many years, has resigned to become geologist for the Taylor Refining Company in San Antonio, Texas.

JOHN C. MAY, district geologist for the Tide Water Associated Oil Company, Bakersfield, California, has resigned to become a consulting geologist.

WILLIAM H. TWENHOFEL, professor emeritus at the University of Wisconsin, will be a visiting lecturer during the spring semester at the University of Tulsa.

HUGH A. STEWART, division manager for The Texas Company at Denver, Colorado, is president of the Rocky Mountain Oil and Gas Association.

DAN O. HOWARD has resigned from the Oil and Gas Conservation Department of the Oklahoma Corporation Commission where he was geologist and petroleum engineer for

about 15 years. He is now employed as a gas engineer for the Warren Petroleum Corporation, Tulsa, Oklahoma.

ALFRED G. FISCHER has changed his address from Columbia University, New York, to Department of Geology, University of Rochester, Rochester, New York.

B. P. HARDER has resigned from the A. A. F. School of Photography, Lowry Field, Denver, to accept a position as geologist with the Geophoto Services, Denver, Colorado.

C. M. LINEHAN has resigned from the Standard Oil Company of Texas, Wichita Falls, and has joined the geological staff of the Superior Oil Company, Midland, Texas.

PARK STAFFORD is chief geologist and engineer of the Continental Consolidated Corporation, Long Beach, California.

JOHN F. DODGE has resigned his position as president and manager of the Pantepec Oil Company of Venezuela, at Caracas, and is returning to engage in the general consulting petroleum engineering business at 459 South Lucerne Boulevard, Los Angeles, California.

D. C. NUFER, formerly with the Burke-Greis Oil Corporation, is with the Deep Rock Oil Corporation, Tulsa, Oklahoma.

H. N. HERRICK has retired from the California Research Corporation. His address is 1836 Capistrano Avenue, Berkeley, California.

CALDWELL STARKEY, formerly with the Stanolind Oil and Gas Company, has a consulting office at 703 Petroleum Building, Wichita, Kansas.

S. SPENCER NYE should be addressed in care of Mrs. Clarence Deems, Jr., 200 Birch Street, Alexandra, Virginia.

FRED L. WHITNEY is no longer with the Carter Oil Company. His address is Box 326, Fort Lupton, Colorado.

CHALMER J. ROY has resigned as associate professor of economic geology at the Louisiana State University, Baton Rouge, effective January 24, 1948, to become professor of geology and head of the department of geology at the Iowa State College, Ames, Iowa.

P. E. NOLAN has resigned his position as chief geologist for the Mene Grande Oil Company, Caracas, Venezuela. His address is 1034 Yale Avenue, Sarasota, Florida.

MYRON C. METCALF, Of Oklahoma City, Oklahoma, is associated with the Wood River Oil and Refining Company.

Newly elected officers of the Kansas Geological Society, Wichita, Kansas, are: president, LAURENCE C. HAY, consulting geologist; vice-president, DON W. PAYNE, Sinclair Prairie Oil Company; secretary-treasurer, ALICE M. QUESENBERY, Cities Service Oil Company; member of executive committee, H. HAROLD TRAGER, Atlantic Refining Company.

ABE TRAVIS, of the Gled Oil Company, Tulsa, died at Ardmore, Oklahoma, December 13. His age was 40 years.

The War Department Special Staff, Personnel and Training Branch, has the following position openings in Japan: petroleum engineer; geologist-geophysicist and a number of

chemical, mining, and metallurgical positions, with Civil Service ratings from CAF-10 to P-6, carrying salaries ranging from $5,657 to $8,877 a year. Details of any of these positions may be obtained upon request. It is suggested that anyone interested submit to this office three copies of Standard Form 57, Application for Federal Employment, which may be procured at any post office. This information comes from ARTHUR W. HODGES, JR., Lt. Colonel, GSC, Branch Executive.

HANS E. THALMANN, formerly with the Socony Vacuum Oil Company, is chief paleontologist for the Venezuelan Atlantic Refining Company at Caracas, Venezuela.

L. L. NETTLETON, author of the book *Geophysical Prospecting for Oil*, gave a paper on "Geophysical Surveys," emphasizing gravity interpretation of the Mississippi salt-dome basin, at a meeting of the Shreveport Geological Society, at Shreveport, Louisiana, December 15.

HAROLD F. PIERCE of the Shell Oil Company, Inc., is now district engineer for Nome headquarters unit offices at Nome, Texas.

RAYMOND M. THOMPSON returned to Laramie in November for the Fuels Section of the United States Geological Survey after an absence since May. He spent the summer on the Utukok River, Northern Alaska, working out the stratigraphy and structure of the western part of Naval Petroleum Reserve 4.

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J. R. WYLIE, JR.
JAMES F. SWAIN

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Monthly meetings. Visiting geologists are welcome.

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Evening dinner (6:30) and technical program (8:00) first Tuesday each month or by announcement.

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Meetings will be announced.

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KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

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Independent, 703 Union Natl. Bank Bldg.
Vice-President - - - - - - Don W. Payne
Sinclair Prairie Oil Company
Secretary-Treasurer - - - Alice M. Quesenbery
Cities Service Oil Company

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Noon luncheons, first and third Monday of each month at Wolf's Cafeteria. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka. Visiting geologists and friends welcome.

LOUISIANA

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NEW ORLEANS, LOUISIANA

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Vice-President and Program Chairman - - -
- - - - - - - - - - - - Joe B. Hudson
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Secretary-Treasurer - - - - D. N. Rockwood
Union Producing Company, Box 1628

Meets the first Monday of every month, October-May, inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

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Ricou-Brewster Building
Secretary-Treasurer - - - - Richard T. Chapman
Stanolind Oil and Gas Company, Box 1092

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

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Treasurer - - - - - - - - - W. B. Neill
Stanolind Oil and Gas Company

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

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Secretary-Treasurer - - - Harry J. Hardenberg
Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing
Business Manager - - - - - - Jack Mortenson
Sohio Petroleum Company, Mt. Pleasant

Meetings: Monthly, November through May, at Michigan State College, East Lansing, Michigan. Informal dinners at 6:30 P.M., followed by discussions. Visiting geologists are welcome.

MISSISSIPPI

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Vice-President - - - - - - - - R. D. Sprague
Sinclair Wyoming Oil Company
Secretary-Treasurer - - - - - Carl F. Grubb
Superior Oil Company
Tower Building

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

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Phillips Petroleum Company, Box 958
Secretary-Treasurer - - - - - W. R. Johnson
The Texas Company, Box 539

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

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OKLAHOMA CITY, OKLAHOMA

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Vice-President - - - - - - - Ben F. Baldwin
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Secretary - - - - - - - - - L. R. Wilson
Carter Oil Company
1300 Apco Tower
Treasurer - - - - - - - - R. W. Edmund
Globe Oil and Refining Company

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon. Y.W.C.A.

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Atlantic Refining Company, Box 169
Shawnee

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

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Secretary-Treasurer - - - - - V. L. Frost
Ohio Oil Company, Thompson Building
Editor - - - - - - - - - - Robert F. Walters
Box 661, Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

PENNSYLVANIA

PITTSBURGH GEOLOGICAL SOCIETY
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Gulf Research and Development Co., Box 2038
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111 Haldane Avenue, Pittsburgh 5

Meetings held each month, except during the summer. All meetings and other activities by special announcement.

TEXAS

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Secretary-Treasurer - - - - - Robert J. Gutru
Cities Service Oil Company, Box 350

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

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c/o O. G. McClain, 224 Wilson Building

Regular luncheons, every Thursday, Terrace Annex Room, Robert Driscoll Hotel, 12:00. Special night meetings by announcement.

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The Atlantic Refining Company
P.O. Box 2819
Executive Committee - - - - Barney Fisher
Comanche Corporation
406 Continental Building

Meetings: Monthly luncheons and night meetings by announcement.

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Phillips Petroleum Company
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Geir-Jackson Company, Inc.

Luncheons: Each week, Monday noon, Blackstone Hotel.

Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

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Pure Oil Company
Box 2107

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

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Secretary-Treasurer - - - Joseph W. McDonald
Shell Oil Company, Inc., Box 2010, Radio Bldg.

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Y.W.C.A. Evening meetings by special announcement. Visiting geologists and friends are cordially invited to all meetings.

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Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

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Secretary-Treasurer - - - Charles F. Henderson
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Meetings will be announced.

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South Penn Natural Gas Company
Union Trust Building, Parkersburg, West Virginia

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Daniel Boone Hotel.

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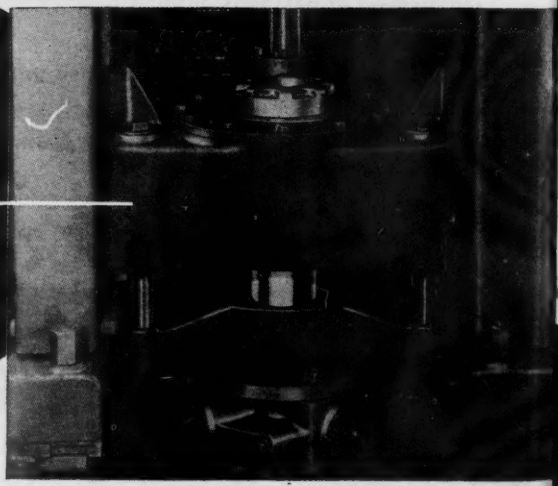

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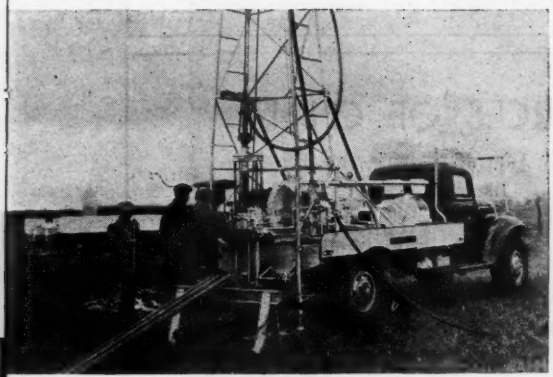

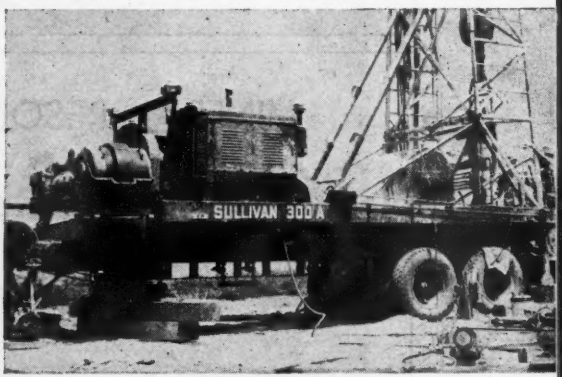

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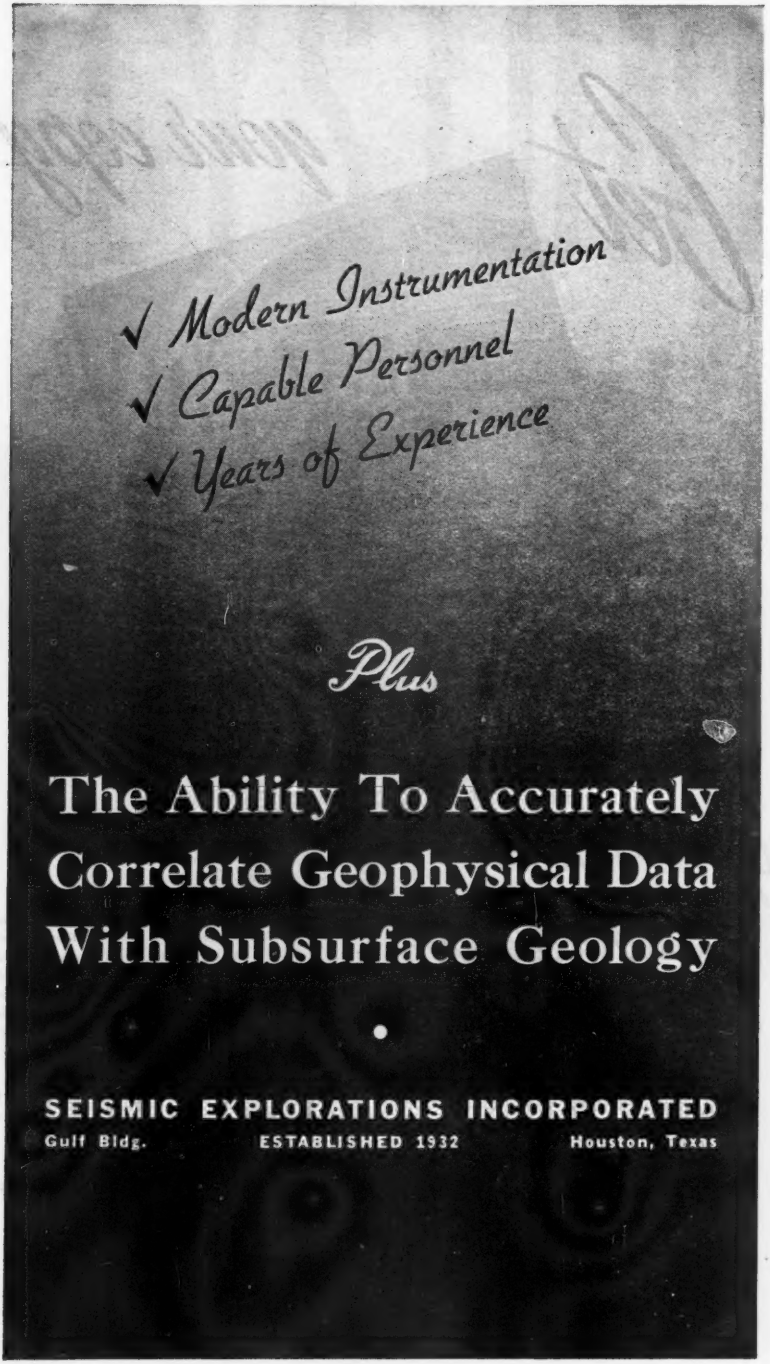
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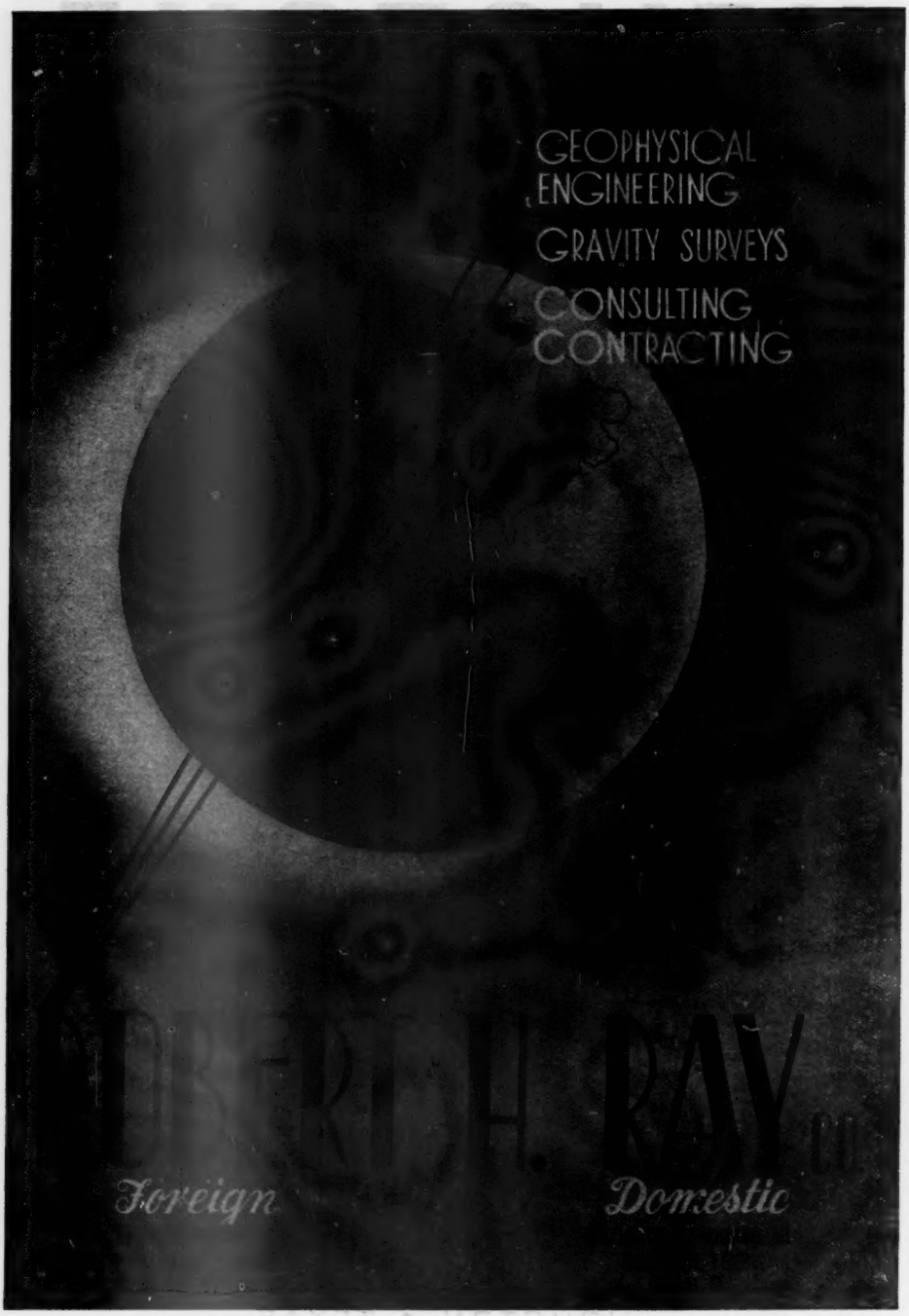
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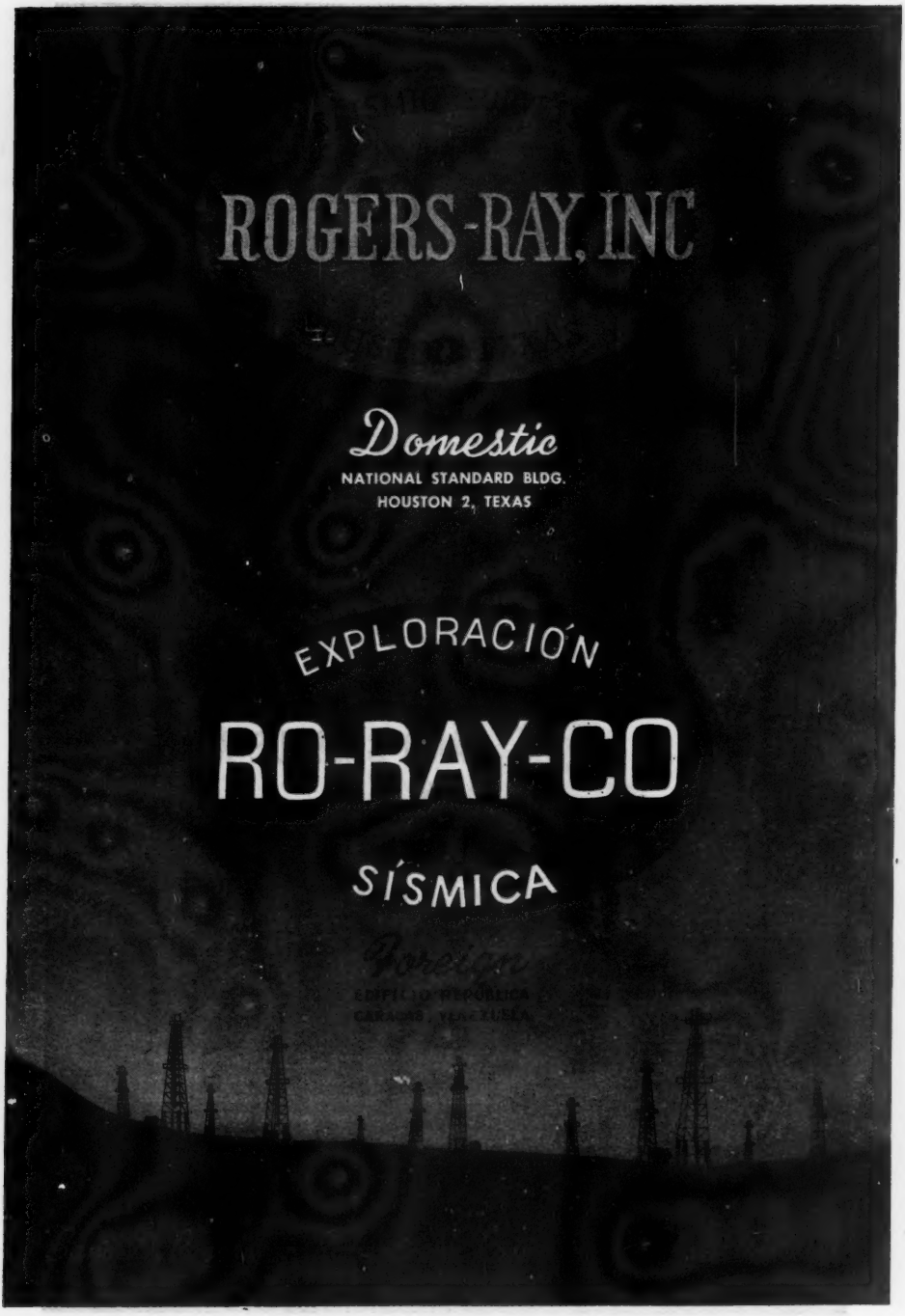
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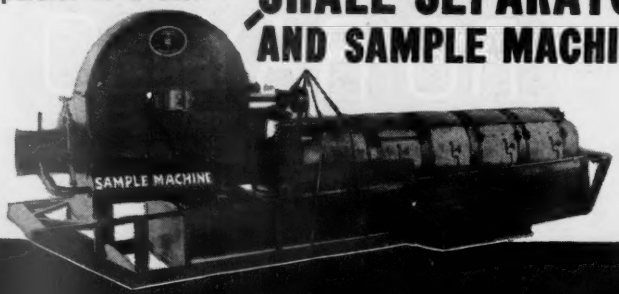

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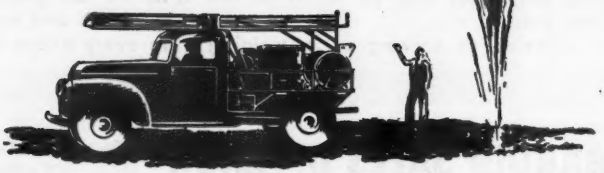

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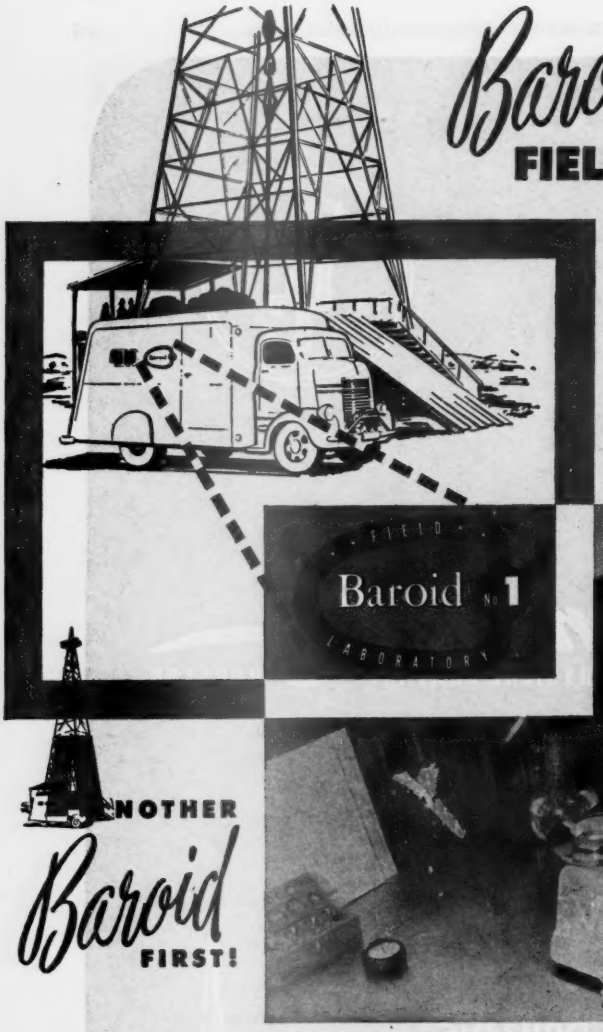

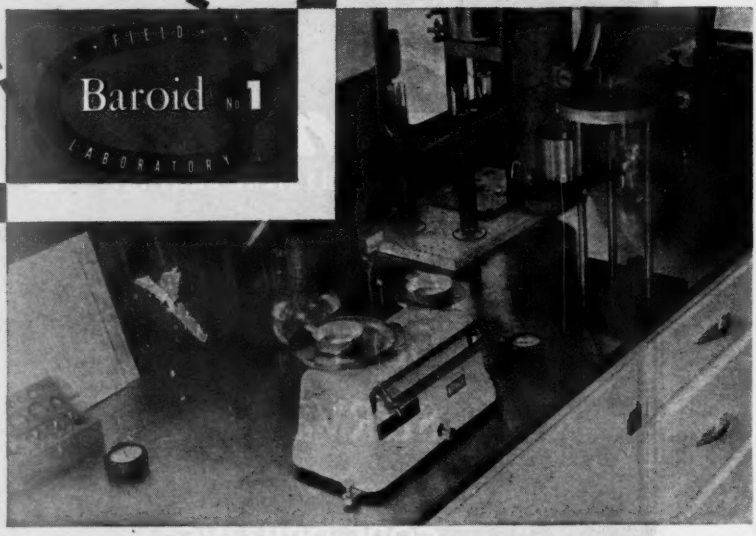

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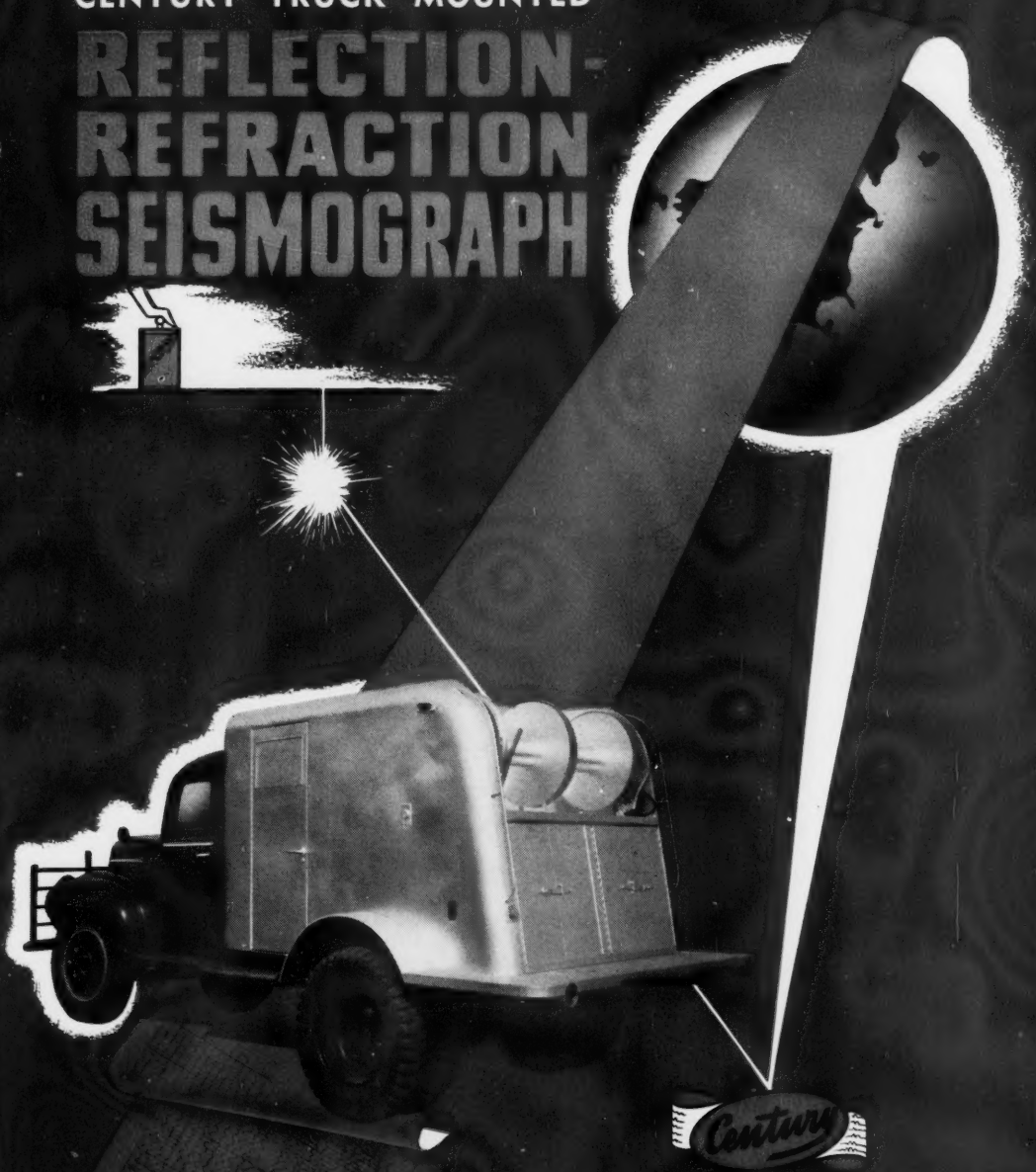

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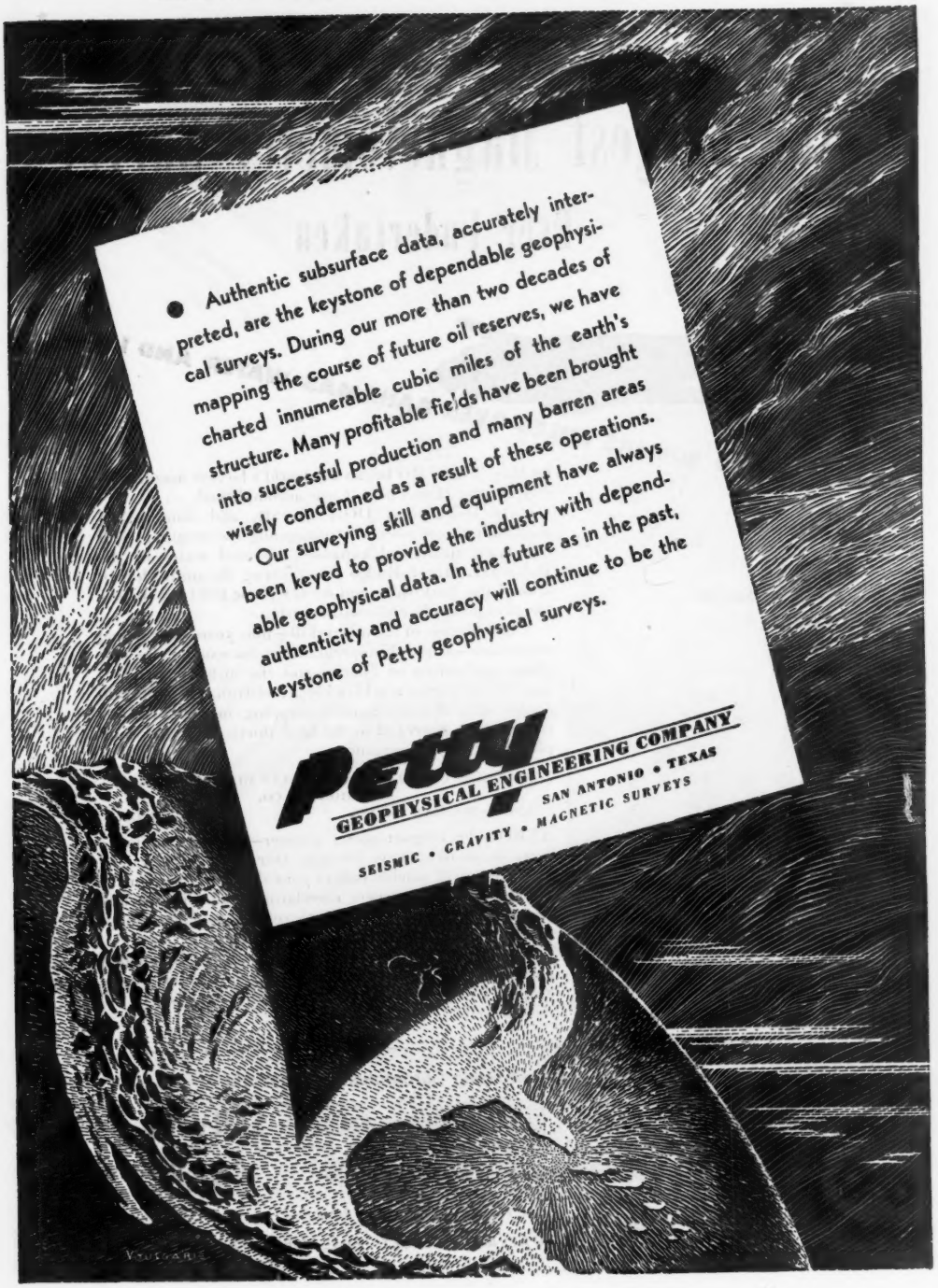
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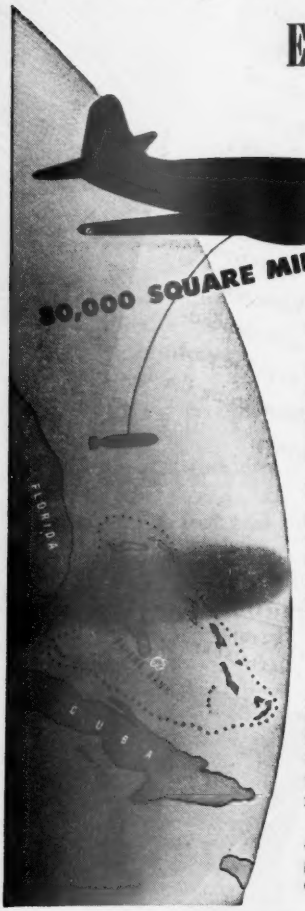

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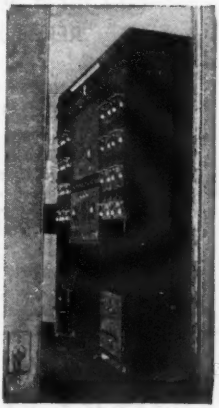

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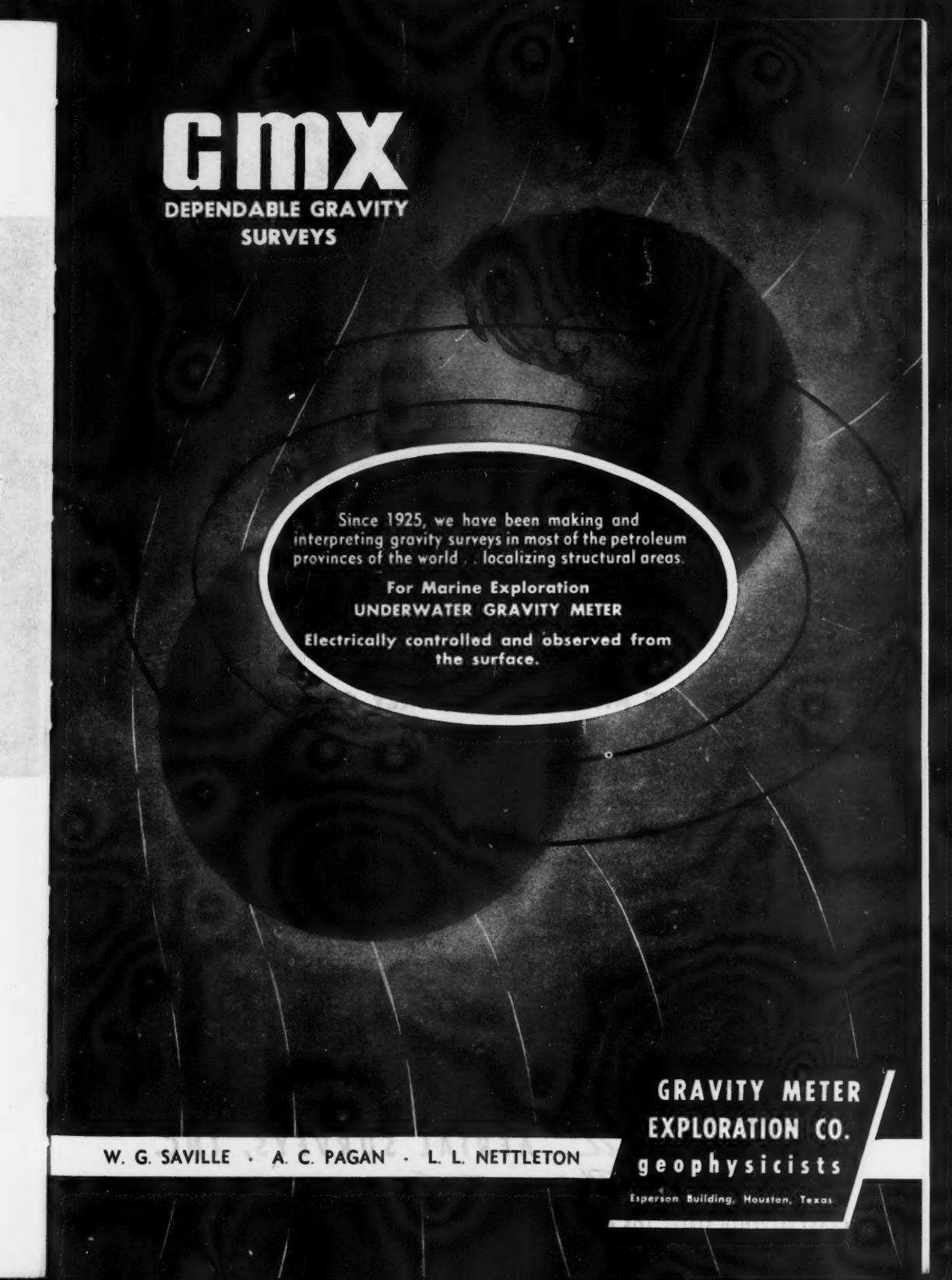
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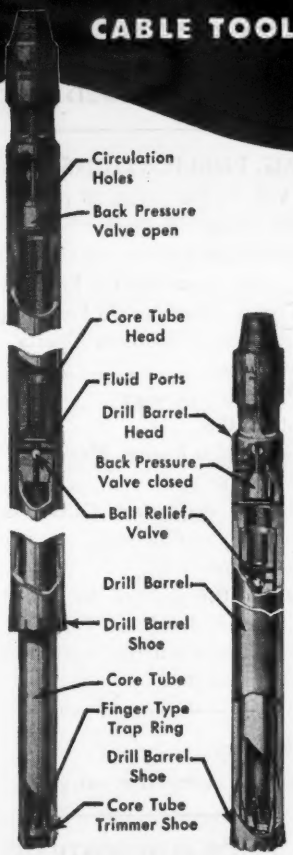

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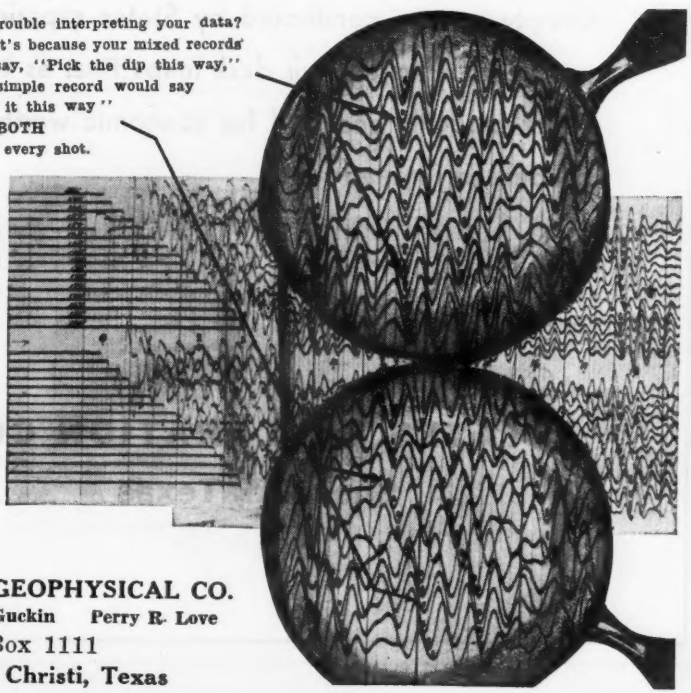

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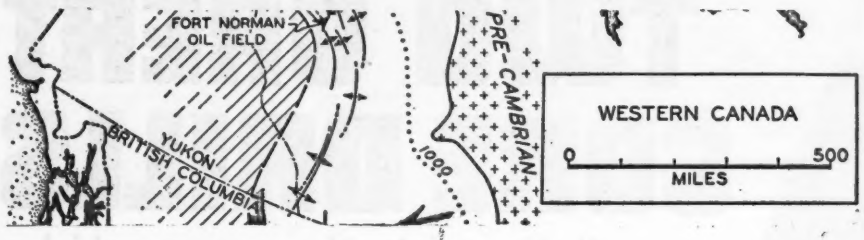

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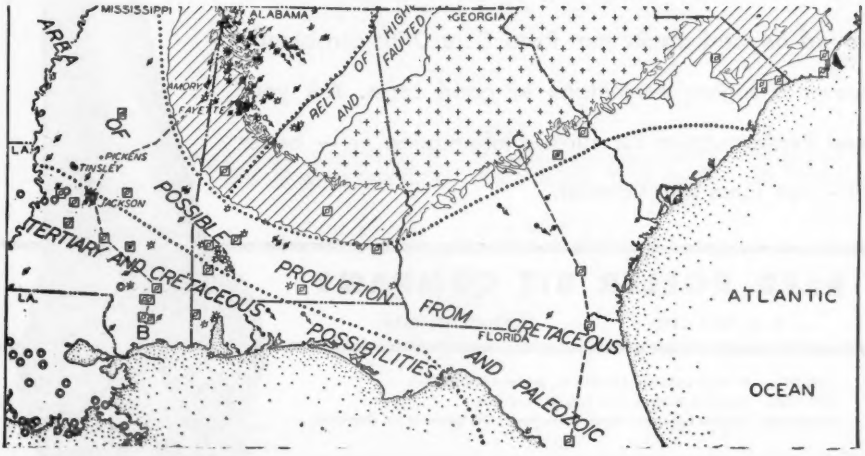

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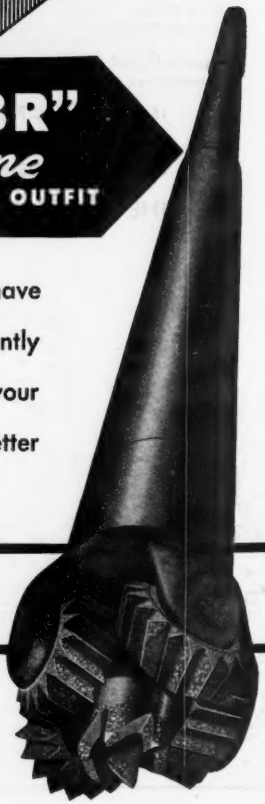

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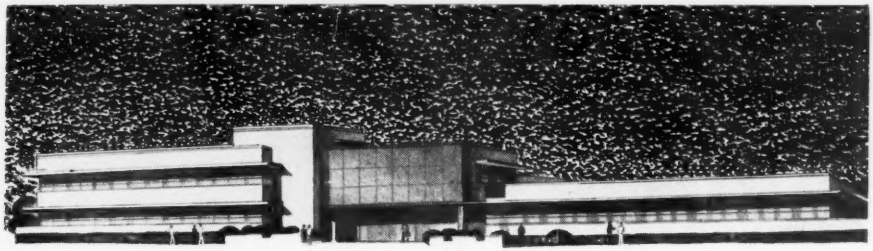

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